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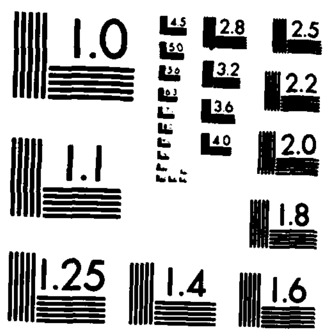
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AN ANALYSIS OF THE EFFECT OF PROCESS CONTROLS ON PRODUCTIVITY AND WEAPON SYSTEM COSTS IN DOD PROCUREMENT

THESIS

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THESIS

Presented to the Faculty of the School of Systems and

Logistics of the Air Force Institute of Technology

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In Partial Fulfillment of the

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Master of Science in Logistics Management

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GM-13

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Preface

The purpose of this study was to develop a descriptive, empirical report of the relationships among quality assurance process controls, productivity and weapon system costs. This purpose was selected because the available literature indicated a growing interest in such relationships, but provided little empirical evidence to support claims about such relationships.

Because of various limitations, this study could only explore the relationships that exist at major DoD aerospace facilities. This exploration was done by way of a detailed interview of key government personnel stationed at randomly selected facilities. The findings reported in this paper indicate the claimed relationships may have basis in fact, but the present DoD surveillance methods do not facilitate validation of the contractor data. Although these results were inconclusive, this topic shows promise for resolving the concerns various interest groups have regarding the control of weapon system costs.

In conducting this study, I received a great deal of support from others. I am most indebted to my faculty advisor, Lt Col Terry Clark, for his patience, guidance and continuing support. I also wish to thank my reader, Maj Art

Rastetter, for his assistance with the style and format nuances of military writing. A word of thanks is also owed those unnamed DoD personnel who participated in the on-site interviews and were most helpful in understanding the complexities of their weapon systems. Finally, I wish to thank my wife Mary and our three wonderful children for their patience, support and understanding during my extended absences from home while pursuing my degree.

Michael W. O'Meara

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Abstract

This Thesis ~~study~~ was a preliminary evaluation of the relationships among quality assurance process controls, productivity and weapon system costs. The available literature indicated positive relationships should exist among the three elements examined, but little empirical evidence was presented to support the positions of the authors. As a result, a detailed interview methodo~~logy~~ was developed to describe the relationships that exist at major DoD aerospace facilities. On-site interviews were conducted at five randomly selected aerospace facilities identified as DoD Plant Representative Offices. The results of this initial study were inconclusive. The examined relationships appeared to be positive, but the cognizant DoD personnel had not validated the contractor data claiming increased productivity and reduced costs associated with adequate process controls. Recommendations are provided to improve the DoD surveillance methods, and possible follow-on research topics are identified.

AN ANALYSIS OF THE EFFECT OF PROCESS CONTROLS ON PRODUCTIVITY AND WEAPON SYSTEM COSTS IN DOD PROCUREMENT

I. Introduction

Justification

This paper reports the results of a graduate-level research project evaluating the relationships among quality assurance process controls, productivity and weapon system costs. The research objectives described in this chapter may have a direct impact on the Department of Defense's efforts to reduce weapon system costs. The investigative questions selected to accomplish the research objectives have generally not been empirically tested by prior research. As a result, this study will determine whether the identified relationship between quality assurance process controls and productivity exists, and ultimately, whether a relationship can be demonstrated between improved productivity and reduced weapon system costs.

General Issue

In April 1981, former Deputy Secretary of Defense Frank Carlucci (5:p.9-140) issued a memorandum about improving the acquisition process for the Department of Defense (DoD). Mr. Carlucci wrote, "A primary objective in streamlining the acquisition process is reducing costs." He was determined to reduce cost overruns in DoD acquisitions.

Efforts are being made by the military services to identify methods to reduce the cost of major weapon systems. Productivity and quality improvement programs have been referred to in the literature (14:Q2; 24:Q2-Q6; 25:15; 31:67) as one approach to accomplish the goal of reduced product costs.

Problem Statement

The issue identified in the preceding paragraph could generate a multitude of studies. In narrowing the topic for this research project, two specific research questions were developed from the general issue:

1. Are DoD in-plant personnel aware of a relationship between quality assurance process controls and productivity?

2. If such a relationship exists, are associated cost savings passed on to DoD in future weapon system procurements?

Investigative Questions

To evaluate the research questions identified in the preceding section, the following investigative questions were tested during this study:

1. How do DoD in-plant personnel evaluate contractor control of production and manufacturing processes?

2. How do DoD in-plant personnel evaluate the contractor's cost controls?

3. If the DoD in-plant personnel evaluate the process controls, how do they define a relationship between such controls and productivity improvement or cost?

4. What data is available to demonstrate relationships among process controls, productivity improvement and reduced costs?

Research Objectives

The preceding investigative questions were designed to measure the extent of DoD awareness regarding contractor quality assurance controls over production and manufacturing processes. The ultimate objective of this study was an evaluation of the relationship of such controls to productivity and cost. A secondary evaluation addressed the issue of whether DoD in-plant personnel use their knowledge of these relationships, if they exist, to assure reduced procurement costs for DoD weapon systems.

According to Emory, some of the typical objectives of a research study include:

> (1) descriptions of phenomena or characteristics associated with a subject population, (2) estimates of the proportions of a population that have these characteristics, [and] (3) discovery of associations among different variables . . . [13:91].

The research objectives of this study provided an opportunity to test the criteria identified by Emory. As noted at the beginning of this chapter, empirical testing of this study's investigative questions has not been reported in the literature. As a result, the research objectives of this report were accomplished by means of a descriptive study. Emory (13:91) noted that such studies provide the opportunity to learn the who, what, when, where and how of a topic.

Overview of the Research Topic

In 1981, former Deputy Secretary of Defense Frank Carlucci issued 32 initiatives for improving the DoD acquisition process. One of the major objectives of these initiatives was to reduce the cost of major weapon system acquisition (5:p.9-138). One of the specific decisions (recommendation 5) supporting this objective was "to encourage capital investment to enhance productivity [5:p.9-151]." The documentation supporting this decision cited the low profit associated with DoD contracting as one contributor to the low rates of capital investment (5:p.9-151).

The Carlucci initiative identified in the preceding paragraph tied contractor profits to increased productivity, and increased productivity to reduced weapon system costs. The current literature contains a number of citations (14:Q2; 24:Q2-Q6; 25:15; 31:67) claiming a relationship

between effective quality assurance, productivity improvement, and product or weapon system costs. These relationships will be described in detail in the literature review contained in Chapter II.

MIL-Q-9858A, Quality Program Requirements, issued in 1963, recognized the relationship between quality and cost (39:1) and required that the "[quality] program shall facilitate determination of the effects of quality deficiencies and quality costs on price." MIL-Q-9858A also described the essential elements for assuring product quality. One of the key elements listed in MIL-Q-9858A is production (or process) control (39:6). Process control is also frequently cited (24:Q8; 25:15; 29:Q2; 40:44) in the literature as a critical element in productivity improvement programs.

In addition to the DoD concerns brought out in the Carlucci initiative, one general concern voiced in much of the literature (6:1; 8:36; 19:16; 25:14; 28:14; 40:42) was the recognized difference between the quality level of Japanese products and the quality level of American products. Just like MIL-Q-9858A, evaluations of Japanese quality programs (6:4-6; 25:14-15; 40:42-43) have often cited production (or process) control as a key element of product quality. The wide recognition of the value of this control element and its effect on product costs are described in detail in Chapter II of this report.

The references cited in this report are not peculiar to DoD; instead, they present industrial, quality consultant and military issues and recommendations. This research project investigated whether these general issues and recommendations can ultimately be used to reduce weapon system costs.

Definitions

Productivity. Tuttle (32:7) stated, "Defining productivity is particularly challenging because the term has been used in many different ways." He then described productivity from a number of different perspectives. For the purpose of this report, the following elements are considered essential to defining productivity (32:7,11):

> Productivity is the relationship between output and its associated inputs when the outputs and inputs are expressed in real (physical volume) terms.
>
> While economists traditionally define productivity as the ratio of outputs [to inputs] stated in real or physical terms, they sometimes substitute prices or costs for physical volumes.
>
> Most . . . managers would find . . . the economist's . . . definition of productivity to be too narrow. Virtually 9 out of 10 managers would include quality . . . in their definition.

Quality. As defined in MIL-STD-109B (38:section 3), quality is "the composite of all the attributes or characteristics, including performance, of an item or product."

Quality Assurance. DoD Directive 4155.1 (37: enclosure 2) defined quality assurance as:

> A planned and systematic pattern of all actions necessary to provide adequate confidence that materiel, data, supplies and services conform to established technical requirements and achieve satisfactory performance.

Yield. Using the measures most frequently cited in the literature (7:38; 12:App C,para 4.8.2.3; 14:Q2; 26:48; 27:1; 39:3), the yield of a process or manufacturing operation is the percentage of conforming items that complete the process or operation. The number of conforming items is determined by deducting nonconformances from the total items started in the process or operation. Typical nonconformances cited include items that are scrapped, items that are reworked to meet specifications, and those items repaired to a more conforming state.

Scope and Limitations

There are many possible avenues to investigate the cost of DoD acquisitions. This study evaluated one element of a quality assurance program -- process control -- to determine if a relationship exists between it and productivity, and ultimately between productivity and cost.

The topic is further limited by the methodology described in Chapter III. The first limitation occurred by way of the decision to perform the study at aerospace contractor facilities known as plant representative offices of the Department of Defense. Facilities such as as Air Force Plant Representative Offices (AFPROs), Navy Plant Representative Offices (NAVPROs), Defense Contract Administrative

Services Plant Representative Offices (DCASPROs), etc. are frequently referred to by their acronyms in the aerospace community. Chapter III also addresses time and money constraints which limited the number of facilities visited, and resulted in an uncontrolled sampling error associated with the data from this study. However, the impact of this limitation was attenuated by other sampling controls described in Chapter III, so that acceptable levels of data accuracy were ultimately obtained.

One final consideration must be made while addressing the scope of this study. While this thesis study is sponsored by the Air Force Institute of Technology, the research questions and objectives are important to all DoD procurement activities.

Summary of the Following Chapters

Chapter II begins with a review of the literature relevant to this study. This literature review describes a relationship between productivity and reduced costs, and includes process control as the primary means of achieving the desired increases in productivity. The literature review concludes with two subsections that report gains associated with productivity improvement programs and a discussion of the empirical support for the conclusions. Chapter II then continues with a section containing this writer's analysis of the literature, and concludes with a section on the significance of the findings to DoD.

Chapter III is a detailed description of the survey methodology employed in this study. After a short overview of the chapter, the justification for the selected methodology is presented. This section is followed by an in-depth description of the methodology and survey instrument, including a review of the validity and reliability of the approach selected. Chapter III continues with a section describing the study population, and a justification of the representativeness of the sampling technique used to evaluate the population. The data collection plan and survey variables are then described, followed by a concluding section which describes the planned statistical analysis of the sample data.

Chapter IV reports the findings of the survey and provides an in-depth analysis of the results. Like the preceding chapter, this chapter begins with a short overview, followed by a section describing the implementation of the survey and the variations from the planned design. The actual results of the study are then reported, together with a reduction of the data and an analysis of the results in terms of the original investigative and research questions. Chapter IV concludes with a report of the statistical analyses appropriate for the data generated by this study.

Chapter V contains the conclusions and recommendations of this writer based on the results obtained from the survey. After a short overview section, this chapter describes

the significance of the findings in terms of the research questions and the general issue described earlier in this chapter. A third section then describes the practical implications of the results reported in Chapter IV. Chapter V then closes this report with a section containing recommendations for follow-on or revised studies based on the data generated by this report.

II. Literature Review

Topical Literature

Introduction. The overview section in the previous chapter mentioned the DoD concern for enhancing productivity (5:p.9-151). The Carlucci initiative in dealing with this concern associated increased productivity with reduced costs (5:p.9-151), and contained a recommendation to enhance productivity through increased capital investment. The Carlucci memorandum identified a number of causes for the low investment in capital equipment. The memorandum also provided recommendations to overcome these shortcomings by such actions as changing the DoD depreciation methods, and supporting the DoD Manufacturing Technology programs.

General Robert T. Marsh, USAF, as the Commander of the Air Force Systems Command (AFSC), was responsible for yearly weapon system procurements worth billions of dollars. General Marsh (22:62) described his concern for weapon system costs at a 1983 Defense Logistics Agency conference on quality. This concern is identical to the concern expressed by Mr. Carlucci in the preceding reference. But, General Marsh proposed a different methodology for addressing their mutual concern, when he emphasized the need for improved quality. General Marsh stated,

> A rather informal look at Air Force contracts, the year before last, revealed that at least $570 million was blown away by scrap, rework and repair, funds that never would have been wasted had quality been designed-in from the start.

The National Research Council's Committee on Navy Shipbuilding Technology (7:p.v) combined the Carlucci and Marsh methodologies into a perspective that linked quality and productivity. Like Carlucci, their study of productivity changes in Navy shipbuilding recognized the utility of DoD's Manufacturing Technology programs in improving productivity as well as quality.

This research project will ultimately address the combined effects of quality and productivity on weapon system costs. An evaluation of the relevant literature to determine if a relationship exists between capital equipment and productivity begins on the next page. This narrow perspective is then broadened by reviewing the conclusions of various authors who describe the role such equipment plays in process control and the relationship of process control to quality. Finally, additional elements of process control, identified by the various authors, will be considered to determine their impact on quality and productivity. All of the identified elements of process control will be evaluated in the research methodology described in Chapter III.

Productivity and Capital Equipment. Like Carlucci, Japanese planners believe there is a relationship between capital investment, depreciation, tax benefits and productivity (28:15). A Quality magazine interview with Mr. Joji Arai, Manager of the Japan Productivity Center (28:18), provided a comparison of the Japanese and American tax benefits associated with depreciation of new equipment. In part, Mr. Arai stated:

> Depending on the type of investment, you can have depreciation of up to 14 percent in the first year in excess of regular depreciation. Those tax systems certainly help the Japanese invest more [than American companies] in the plant, new equipment and especially in research and development [28:15].

T. J. Murrin, President of the Public Systems Company, Westinghouse Electric Corporation, has responsibility for the subsidiary Defense System Center contracts. At the 1982 Annual Quality Congress, hosted by the American Society for Quality Control (ASQC), Mr. Murrin described his company's efforts to improve quality and productivity (25:14). Mr. Murrin went on to provide some insight to the Westinghouse philosophy regarding new equipment, when he stated, "Another strategy is the introduction of improved technology to let us do the job right with the right tools."

The U.S. Air Force supports Murrin's beliefs regarding the role of new capital equipment. In the Air Force guidance to their Technology Modernization (Tech Mod) program, they state:

> The primary objective of Tech Mod is to improve the overall health of the industrial base through implementation of manufacturing technology and improved capital investment. The resulting improvements in productivity generate numerous benefits for both the Air Force and the private sector, including: reduced costs; improved quality . . . [12:1-3].

Rear Admiral Frank C. Collins, USN, was Executive Director of Quality for the Defense Logistics Agency (DLA). Admiral Collins (6:9) provided a different perspective regarding capital equipment when he described DoD's inability to invest in new equipment:

> Regrettably, we are still recycling 1950's technology in our Industrial Plant Equipment (IPE) program, in which DLA pays for installation and maintenance of equipment for defense industries that thus escape, over the short term, the tough decisions to retool to modern technological state of art.

<u>The Role of Capital Equipment in Process Control</u>. Don Curtis, the manager of Hewlett-Packard's Disc Memory Division, echoed Admiral Collins' views and also tied these efforts to cost savings (24:Q8). Mr. Curtis continued by describing the justification process for new equipment used at the Hewlett-Packard Disc Memory Division:

> One of the key philosophies involves automation. We originally justified the investment in automation merely on the basis of how fast we could recover through reduced direct labor costs. We now have a list of eight reasons to automate production -- and number eight is justified labor . . . the second one is process control -- quality.

The use of capital equipment in process control was one of the objectives of the Air Force Tech Mod program cited above. In an Air Force sponsored study, Gossard, et al (15:5-8) described the effects of new designs and techniques

that can be used with capital equipment. The process control technique they tested was described as adaptive brake-forming of sheet metal parts. They found some of the potential benefits of this method of process control were increased part accuracy and improved quality control.

Part accuracy is often measured by various types of capital equipment. The advantage of using automated capital equipment in quality control testing was described by Craig Walter, another Hewlett-Packard manager:

> The automatic test system also obviates the need for final QA, as it is presently known. The role of final QA becomes one of insuring the integrity of the process instead of screening the product [40:44].

Automation is not without its drawbacks. An article in Quality magazine reminded those who see automation as a panacea: "Automating an operation [or process] that is not in control assures the quick and consistent manufacture of defective product [29:Q2]."

Defective product, as will be illustrated in the following subsections, contributes to increased costs. As a result of this drawback, this study will evaluate more than just the role of automation in process control. The following subsections describe some of the other elements cited as essential to improved process control and increased productivity.

An Expanded View of Process Control. The last eight citations address only one component of process control -- capital investment. In addition to this component identified in the Carlucci initiative (5:p.9-151), there are many other facets of process control. For example, a number of sources emphasize the necessity of understanding the spread or variability of the process (3:27-86; 16:72,91; 31:64,82,240; 40:43-44). Statistical analysis is essential at this point. As long as the engineering or design tolerances are compatible with the process capability, production yield will be maximized.

Broh (4:53-59) covered other facets of process control when he emphasized equipment capability must be monitored to assure accuracy and precision are maintained throughout the life of the process. He also noted that operating environment and maintenance must be considered by the quality planner evaluating a process. And finally, he reported that the equipment set-up techniques must be considered when the machine is used for manufacturing more than one product.

Keith McKee (23:20), Director of the Manufacturing Productivity Center of the IIT Research Institute, pointed out the need to monitor the condition of the tooling used with the manufacturing equipment. "By monitoring tool wear and position . . . companies can obtain the knowledge they need to adjust the tools or stop the process before bad parts are made."

Relating Process Controls to Productivity and Profits. The preceding citation identified the ultimate goal of improved process control -- to increase productivity by assuring the manufacture of quality parts. Don Curtis (24:Q2-Q6) described this relationship when he stated,

> Quality is the maintenance of a designed-in level of reliability through high standards, workmanship and process control. Productivity is just an extension of quality. Quality improvement automatically increases productivity -- you don't have to do anything else.

Murrin (25:15) and Squires (31:67) reversed this logic in describing the absence of process control as the cause of increased cost. Fiegenbaum (14:Q2) supported this position, illustrating the situation that exists when quality improvements are not evident:

> Industrial practices based on traditional concepts have created a "hidden plant" that drains as much as 40 percent of an operation's productive capacity. This plant exists to replace products recalled from the field, to retest and reinspect rejected units, [or to] rework unsatisfactory parts.

The Committee on Navy Shipbuilding Technology identified a similar conclusion regarding the effect of quality on weapon system costs. They (7:38) first described the result of improved quality performance, which they believed precluded the need for rework and repair. They further noted, "Rework and repair, in addition to adding to costs, usually must be done in a less efficient manner than was done in the first place."

The last two citations refer to elements that are included in this study's definition of yield. These same elements are found in MIL-Q-9858A (39:3,7) and MIL-STD-1520A (11:5), and reflect just some of the costs or losses identified by an adequate quality program (20:47). Puma (27:15) described the role quality data can play in determining both quality effectiveness and productivity. Unfortunately, MIL-Q-9858A permits the contractor to determine what quality cost data will be maintained. While this factor is beyond the scope of this study, it could lead to inconsistencies in measuring the effectiveness of process controls. As a result, this issue will be addressed as one of the proposed follow-on studies described in Chapter V.

Reported Gains. Although the preceding remarks have implied a relationship between quality elements and productivity, the approaches of most of the authors reviewed to this point were philosophical. They did not cite the measure of productivity used to support their conclusions. Their reports did not contain empirical evidence to support their conclusions; but, as noted below, some did report gains associated with their recommended approach.

Murrin (26:47) stated the Westinghouse Public Systems Company "has achieved a seven percent annual productivity increase over the past three years." He also described an example of how his company's approach was implemented on a printed wiring assembly program:

> Statistical techniques were used to determine the priority of each problem based on its effect on yield. In the first year, the number of wiring assemblies -- passing all process steps without needing any rework -- has climbed dramatically. And productivity is up more than 35 percent [26:48]!

Walter (41:23-24) described the effect of Hewlett-Packard's quality assurance program at two different facilities. At the Loveland Instrument Division, "Wave soldering nonconformances were reduced from a few tenths of a percent to 200 ppm." This reduction in defects translated to increased process yield which, by definition, is another measure of increased productivity. Walter continued to describe the Hewlett-Packard improvements by citing their success at Yogahama/Hewlett-Packard:

> Production costs have declined by more than a third. Their inventory has been reduced by two-thirds . . .. The average yield failure rate of our products has been reduced about 16% per year [41:23-24].

Empirical Studies. As noted in the preceding subsection, the available literature contains a shortage of empirical studies relating process control to productivity or product costs. To date, this author knows of only five empirical studies which considered any of the topics covered above. The first such study was a master's thesis by Heffner and Weimer (18) that sought to determine which factors motivated government subcontractors to undertake capital equipment investments. Heffner and Weimer found the most significant factor to be the "opportunity to provide a

better quality product [18:82]." However, this study made no attempt to correlate this finding with productivity or cost data.

The second empirical study was an analysis of new sheet metal forming methods by Gossard, et al (15). This study did report the estimated saving associated with adaptive brakeforming (15:45-46), but their calculations only considered reductions in set-up time for the brakeforming process. While such measures are often used in calculating productivity, they are beyond the scope of this study. Gossard, et al did report other potential benefits, including improved quality, but the savings associated with such benefits were not tested.

The third empirical study was a report of the F-16 Tech Mod integrated quality assurance plan by Puma (27). He reported (27:27-28,45-50,60-70) significant reductions in reject rates for rotational machining operations and numerical control punch presses. The associated reductions in scrap and rework were of the magnitude of 50-80%, and Puma stated this translated to a reduction in discrepancy cost. The reported reductions were achieved solely through improved inspection and corrective action methods, without significant investment in new capital equipment. This limitation has been considered by this author, and the Puma methods will be evaluated along with the other elements of process control described in the preceding subsections.

The fourth study was a master's thesis by Kruse and Taras (21) that evaluated the relationship between the quality of delivered products and DoD procurement policies and procedures. Their study was based on available government data regarding defective items shipped to the San Antonio Air Logistics Center (ALC), and shipments made under the cognizance of Defense Contracts Administrative Services Management Area (DCASMA) Dayton. One finding reported by Kruse and Taras was that contract quality performance was independent of the type of quality inspection clause (e.g., Mil-Q-9858A), but more unacceptable lots occurred when the inspection clauses reflected a more complex product (21:42). They also identified other factors which had an adverse effect on the quality of spare parts delivered to the San Antonio ALC (21:79) -- such as competitive market environment, type of solicitation and relative size of the contractor. One final finding reported by Kruse and Taras was that the role of DCASMA Dayton regarding defective products was reactionary (21:80-81). When defective products were reported by the using activities, DCASMA Dayton increased the amount of government corrective action; but, when the DCASMA Dayton quality personnel rejected more product prior to shipment, the number of defective product reports from the users decreased. In general, the factors affecting product

quality reported by Kruse and Taras did not address the elements of process control identified above, and they are thus beyond the scope of this study.

The final empirical report was a master's thesis by Berry and Bland (2) that proposed a model to measure the relative productivity of individual DoD contractors. Their model based the measures of productivity on past performance in terms of input and output costs (2:4-5,27). While their measures employed some of the same elements of productivity as the definition provided in Chapter I, in application, Berry and Bland's measures only incorporated one of the process control elements addressed earlier in this literature review. They used capital equipment costs in two separate calculations for their model (2:41), but they found that simple measures of productivity could not be accepted without further examination of economic implications (2:85). Berry and Bland went on to recommend that their model be used in conjunction with data on scrap and rework costs to determine the productivity associated with Air Force Tech Mod programs (2:90). However, they did not test this recommendation, so no general conclusion can be drawn from this facet of their study. The role of scrap and rework as a measure of productivity will be evaluated as an element of process control in the methodology of this study, with resultant empirical data reported in Chapter IV of this study.

Summary of the Literature

The literature implies that productivity gains from improved quality assurance are not only possible, but in at least one nation -- Japan -- have proven to be feasible. The leaders of American industry seemed to agree with these views and appear motivated to respond to the challenge. Many of the sources cited above indicated that one approach to improving productivity would be to develop improved process controls which should lead to reduced product costs.

The means of accomplishing the desired improvements were also addressed. The literature cited recognized the need to modernize and maintain the capital equipment as a source of assuring better process control. While modern capital equipment is only one element of process control, according to Heffner and Weimer, contractors appear to recognize it's role in improving the product quality.

A relationship between effective process control and reduced costs was implied in the literature cited above, but only Puma reported actual data to support the relationship. However, the Puma study only considered a limited range of control elements. As a result, it can only be stated that quality improvements generated as a result of process controls may increase productivity. The effect of the increased productivity on product costs or profits has not been empirically tested, nor has it been demonstrated that reduced costs were passed on to the Department of Defense.

Significance of the Findings to DoD

One serious shortcoming of the literature reviewed to date is the lack of empirical evidence. Few of the sources reported were legitimate research studies. The controls used to test the hypotheses were not described. A second shortcoming of the literature is the lack of data to demonstrate that cost savings were passed on to DoD.

As a result of the shortcomings identified in the preceding paragraph, this study will attempt to evaluate the relationships among process controls, productivity and cost. As described in the methodology outlined in the next chapter, this evaluation will be accomplished by conducting interviews with government personnel stationed at aerospace plant representative offices.

This approach will provide some measure of the awareness of DoD personnel regarding the role of contractor quality controls over production processes. This study will also demonstrate whether a relationship exists between those quality measures and increased productivity, and ultimately, whether a relationship exists between such controls and reduced weapon system costs.

III. Research Methodology

Overview

The literature review, contained in Chapter II, concluded that there was little empirical evidence relating process controls to productivity and cost. This shortcoming led to the selection of the methodology described below. This methodology will provide answers to the following research questions:

1. Are DoD in-plant personnel aware of a relationship between quality assurance process controls and productivity?

2. If such a relationship exists, are associated cost savings passed on to DoD in future weapon systems procurement?

The approach selected for evaluating these research questions is a detailed survey of randomly selected aerospace facilities known as DoD plant representative offices. The next section of this chapter describes why this methodology was chosen. This justification section is followed by a third section containing the details of the survey methodology. The actual survey instrument is described in this third section, together with a review of the validity and reliability of the proposed approach.

This chapter continues with a section describing the population to which the results of this study apply. The sample selection approach is also identified in this section, together with a justification of the representative-

ness of the sample. The fifth section of this chapter describes the data collection plan, and includes identification and classification of the survey variables, evidence of data validity, and assumptions and limitations of the plan. Finally, this chapter concludes with a section describing the planned statistical analysis of the sample data.

Justification for the Method

Analysis of the literature reviewed in Chapter II indicated that no solution has been developed to satisfy the research questions listed in the preceding section. The conclusion of Chapter II identified two shortcomings of the available literature. These shortcomings were the lack of empirical data relating process controls to productivity and cost, and the fact that no evidence was presented to demonstrate that cost savings were passed on to DoD. As a result, this study was designed to gather data which will allow future development of hypotheses to test whether process controls are related to productivity and cost. The data was collected by means of structured personal interviews developed around the investigative questions described in Chapter I. More details regarding the interview instrument are provided in the next section.

The structured interview approach was selected for two reasons. First, the structured interview is considered an excellent data collection technique (13:293-294). Emory listed several advantages of this method, emphasizing:

The greatest value of this method is the depth and detail of information that can be secured. It far exceeds, in volume and quality, the information we can usually secure from telephone and mail surveys.

The second reason for selecting the personal interview methodology was the time constraint on this thesis project. A written survey, to be sent to personnel within DoD, must be approved by four organizations, up to and including the Air Staff at the Pentagon (1:120). This approval cycle is a time-consuming process and, in light of the previously identified benefits of the proposed method, is considered unnecessary.

The proposed method is not without its disadvantages. Emory (13:294) noted, "the method is costly, both in money and time." However, the time issue associated with this method is less than that associated with written surveys, as this survey instrument only required two levels of local review (1:119). The money constraint did present a problem, since the proposed respondents were located throughout the continental United States (CONUS).

The most significant hurdles associated with the methodology selected were the costs of traveling to the personal interviews, and the development of an accurate measuring instrument. The first issue was resolved by obtaining approvals in the manner specified in the AFIT _Graduate Management Program Handbook_ (1). The second issue is addressed in later sections of this chapter.

Interview Instrument

Introduction. The complete interview questionnaire is contained in appendix A to this report. This section describes the salient features of the interview instrument and the rationale for the approach taken in the interviews. The variables to be isolated by the interview questions are also described in this section. This section concludes with a review of the literature regarding the validity and reliability of the selected method.

The interview instrument is arranged to evaluate the four investigative questions identified in Chapter I. Each investigative question is evaluated in accordance with the criteria described in the next four subsections. The investigative questions will not be directly posed to the respondents; rather, an overall evaluation will be based on the composite response to the individual measurement questions associated with the investigative questions. Emory (13:65-66) indicated such a hierarchy is necessary to satisfactorily answer research questions such as those listed above.

The technique used to develop the specific measurement questions is described by Emory (13:238). He stated that measurement questions should generally progress from the simple to the complex, and from general items to more specific items of interest. Emory further stated,

> The objectives of this procedure are to learn the respondent's frame of reference and to extract the full range of desired information while limiting the distortion effect of earlier questions on later ones.

Emory's guidance was instrumental in the development of the sequence of the measurement questions described below. This exhaustive series of questions was intended to capture all the essential data to answer the research questions.

Evaluation of Production and Manufacturing Processes. The first group of measurement questions was designed to investigate the question,

1. How do DoD in-plant personnel evaluate contractor control of production and manufacturing processes?

The investigation was limited to coverage of only three areas of process control: general issues, machining and heat treating operations. This limitation in scope was required because of the complexity inherent in DoD weapon systems, since the number of manufacturing techniques and processes available to contractors is almost unlimited.

The "general issue" measurement questions were intended to identify the respondents' frames of reference regarding process control. These questions initially sought to determine the type of contractual quality requirements levied on the contractor, and the DoD guidance for evaluating the contractor's performance against these requirements. This series of questions then became more specific, so that the elements of process control which may play a role in the government surveillance were identified. The "general issue" questions concluded by ascertaining the respondents' definitions of process control and yield for later development of operational definitions based on this study.

The individual "general issue" questions were based primarily on the elements of process control identified in the literature review in Chapter II. In addition to those sources cited in Chapter II, H50, Evaluation of a Contractor's Quality Program (34), a government document used in conjunction with MIL-Q-9858A, provided the guidance for the question regarding *evaluation of environmental controls.* The objective of these "general issue" questions was to elicit data that has broad application as compared to the measurement questions asked about the machining and heat treating operations.

The "machining operation" questions were developed to measure the level of process control surveillance performed by the government. The questions tended to be much more specific than those listed in the "general issues" section. The sequence of questions was not as important as above, since specificity regarding machining process controls was the objective of this group of measurement questions. However, an attempt was made to present these questions in an operational sequence, proceeding from equipment maintenance through actual machine operation to component inspection. Finally, the "machining" measurement questions ended with an evaluation of how the government personnel evaluate advanced machining process controls.

The controls evaluated in the "machining" section of the interview were also based on those process elements cited in the literature review. In addition to the previous sources, H50 (34:17,25-26) provided reference material to develop the questions regarding production tooling used as a media of inspection and equipment set-up and operation. Bohlen and Sweeney (3:28-31,65-68,71-72) presented information that was used to develop the question on statistical process control, and Puma (27:69) provided additional data on some of the elements of advanced machining techniques.

The measurement questions used to evaluate the level of government surveillance of "heat treating operations" concluded the first section of the interview. Like the preceding section on "machining operations," these questions were organized in a sequential format, proceeding from material preparation through inspection of the processed components. As was true for the "machining" questions, the objective here was to understand how government surveillance is accomplished so that conclusions could be drawn regarding the evaluation of production and manufacturing processes.

The "heat treating" questions presented here were based on the general controls identified in two common military specifications dealing with heat treating of aluminum and steel (35; 36). Regardless of the source material, the questions were designed to measure basic understanding of the features of the process in lieu of the detailed require-

ments of a given specification. This perspective helped to assure the data developed were related to the investigative question listed above.

<u>Evaluation of the Contractor Cost Controls</u>. This subsection describes the second group of measurement questions, which were designed to investigate the question,

> 2. How do DoD in-plant personnel evaluate the contractor's cost controls?

This series of questions began by establishing the contractual framework and definition for control of nonconforming material. This step was necessary because of the correlation that is made in the government specifications between nonconforming material and cost control (11:5,8,12; 39:3). These measurement questions became more specific as they progressed through the elements of nonconforming material to the elements of cost control.

The criteria reviewed in this subsection were based on controls typically required by MIL-Q-9858A and MIL-STD-1520A, as identified in the literature review of this report. In addition to the cited documents, the question regarding the possible savings associated with reduced sample sizes was drawn from Bohlen and Sweeney (3:47,61) and Puma (27:44,72). The final question in this subsection was based on the discrepancy cost criteria contained in H50 (34:13), the government guide to evaluating a contractor's MIL-Q-9858A program.

This group of measurement questions provided data and background for proceeding to the next level of specificity in the overall interview design. Having established a framework for what constitutes government evaluation of process and cost controls, the investigation proceeded to an evaluation of the relationships among those two control elements and productivity.

<u>Relationships Among Process Controls, Cost and Productivity</u>. This third group of measurement questions was designed to investigate the question,

> 3. If the DoD in-plant personnel evaluate the process controls, how do they define a relationship between such controls and productivity improvement or cost?

This investigation was more specific in the overall instrument design than those in the previous two subsections. Like the preceding subsections, the internal sequence within this group of measurement questions flowed from the general to the specific items of interest.

Like the previous investigative sequences, this subsection began with questions designed to establish the framework for the measurement questions that follow. An evaluation of the elements of productivity improvement, as described in the literature review, then followed. The final questions of this subsection sought to determine the relationships among productivity and the process and cost controls evaluated in the preceding investigative sequences.

Successful completion of this set of measurement questions permitted an evaluation of the relationships among process controls, productivity and cost. While this would satisfy the original research question, it would not address the second shortcoming noted in the present literature. This shortcoming -- the lack of evidence that cost savings are passed on to DoD -- is addressed in the final set of measurement questions described below.

Evaluation of Supporting Data. This group of measurement questions was designed to evaluate the final investigative question,

> 4. What data is available to demonstrate relationships among process controls, productivity improvement and reduced costs?

These questions represent the final level of specificity in this interview. As before, the sequence began with questions designed to establish the framework for government analysis of contractor cost data. The sequence continued with an evaluation of the way government personnel assess the reliability of the contractor data identified in the previous subsection. The final two questions sought to determine whether the available data is used to assure reduced costs for the government.

Analysis of the data from the preceding four investigative questions will provide information to overcome the shortcomings of the current literature, as described in the introduction to this section. This report will also provide

empirical evidence to describe the relationships among process controls, productivity and cost. And, the equally important objective of determining whether the relationships among these elements results in reduced weapon system costs will be accomplished.

Personal Data. In addition to the preceding investigative questions, the interview instrument contained five questions to identify the survey respondent. The respondents will remain anonymous; however, this data was collected to assure the respondent can be contacted if necessary for clarification or further discussions. Emory (13:238) recommended that personal questions be included at the end of the interview to reduce the threat or demotivation such questions might cause if asked too soon. He noted, "Questions which are more interesting, easier to answer, and less threatening usually are placed early in the sequence to encourage response and promote rapport [13:222]."

Validity and Reliability of the Interview Instrument. In discussing the validity of personal interviews, Emory (13:214) stated,

> A major criticism of the survey method is that it depends so completely on verbal behavior. The respondent can knowingly give untrue or misleading answers.

But, Emory also recognized that questionnaires such as the one described above are appropriate "when the objective is to discover opinions and degrees of knowledge [13:234]." In consideration of these factors, Emory believed it was incum-

bent upon the researcher to assure the survey instrument selected was an accurate measurement tool, characterized by its validity and reliability (13:128).

To be considered a valid measuring tool, the survey instrument must provide adequate coverage of the topic under consideration. Emory noted, "If the instrument contains a representative sample of the universe of subject matter of interest, then content validity is good [13:129]." Emory further suggested that the best method for assuring the content validity is by having the instrument reviewed by a panel of experts (13:129). This type of review will eliminate the bias caused by inclusions or omissions in the survey, which Emory identified as the greatest source of distortion in surveys (13:226,229). The recommended instrument review was accomplished on this survey instrument, using local experts from the Air Force Institute of Technology faculty. These experts are identified in appendix C to this report, along with a short synopsis of their experience in the areas covered by the survey instrument.

The second characteristic of a good measurement tool is reliability. Emory (13:132) stated, "A measure is 'reliable' to the degree that it supplies consistent results." While this characteristic cannot be determined without some type of preliminary testing, Emory suggested that reliability can be improved by assuring the external sources of variation are minimized (13:134). In a structured inter-

view, the sources of variation are reduced by asking questions in a standardized format and sequence (13:215). The time allotted and the money available for this study did not permit pretesting of the interview instrument. As a result, the reliability of this interview instrument was based solely on the standardized format and sequence of the questions asked of the respondents.

Population and Sample Description

The initial population under consideration was aerospace plant representative offices under the cognizance of various DoD procurement offices. These facilities are often identified by their acronyms as AFPROs, ARPROs, DCASPROs and NAVPROs, and number approximately 80 within the continental U.S. However, when the scope of this study was narrowed to facilities performing in-house machining and heat treating operations, the population became further restricted. To determine the exact population of aerospace facilities performing these specific processes, telephonic contact was made with all plant representative offices listed in DoD 4105.59-H, the DoD Directory of Contract Administration Services Components (33:p.I-1 to I-17). This preliminary contact resulted in a study population of 43 facilities, each of which contained all of the relevant dimensions described below.

The most relevant dimensions of this population were the criteria that the facility must be an aerospace plant representative office listed in DoD 4105.59-H, currently performing the machining and heat treating operations listed in the interview instrument. Another important dimension of the population was the requirement that the potential respondents must be responsible for administering the floor-level quality assurance program within the plant representative office and have knowledge of the use and maintenance of the contractor quality cost controls. This limitation assured selection of personnel with the most current knowledge of the contractors' production and manufacturing process and cost controls.

The preceding limitations resulted in a population characterized by facilities primarily involved in the manufacture of mechanical and structural aerospace systems and subsystems. Typical items manufactured in such facilities include airframes, propulsion systems, actuator systems, etc. Excluded from the population were those facilities which primarily manufactured and fabricated electronic end-items, where all required machining or heat treating operations were subcontracted.

A representative sample of five facilities was chosen using a simple random selection from the identified population. Each plant representative office within the population meeting the criteria established above was assigned a

two-digit number. The sample facilities were identified using the last two digits of a random number table. A random number table contained in a college-level statistics book was considered adequate for this purpose. Alternate sample facilities were also identified in case permission could not be obtained to perform the on-site survey, or some later indication was received that the facility did not meet the relevant dimensions outlined above.

The sampling plan described above helped assure the data generated as a result of this study could be generalized to the identified population. Appendix B of this report list all the facilities that met the population dimensions described above. The next two sections of this chapter provide additional detail on the data collection plan and the statistical tests used to ensure the adequacy of the data developed in this research study. These details must also be considered when evaluating whether the results can be generalized to the population under consideration.

Data Collection Plan

This section contains the details of how the data were collected, as well as the scoring criteria, variable identification and classification, and evidence of the data validity. These details are outlined in the subsections below, and are followed by a final subsection describing the assumptions and limitations associated with this method.

__Specifics of the Plan__. As noted in the preceding sections, the interviews to collect the data were conducted at five randomly selected aerospace facilities identified as government plant representative offices. As described by Emory, "What is called a 'survey' in common parlance is an ex post facto study (without manipulation of variables) in the interrogation format [13:87]." Emory also noted that an ex post facto design allows the researcher to only report what has happened, without any attempt to influence the variables, because manipulation of the variables could introduce bias. This caution does not preclude manipulation of the resultant data, as described in the next section.

As an ex post facto study, this report provides descriptive data to answer the research questions identified above. As noted in Chapter I, the typical objectives of such a study are:

> (1) descriptions of phenomena or characteristics associated with a subject population, (2) estimates of the proportions of a population that have these characteristics, [and] (3) discovery of associations among different variables [13:91].

Emory described a number of methods to assure these objectives were met. Emory also recognized (13:109) that the best research technique to neutralize the confounding affects of other variables -- random assignment of variables in some form of test treatment -- was unavailable in the ex post facto design. But he noted that extraneous variation could be reduced by selecting subjects who possess certain

control characteristics. The control recommended by Emory was achieved at each plant representative office by interviewing respondents considered to be the most knowledgeable of the process and cost controls under investigation. This criterion was met through an introductory letter requesting that such experts be made available, including Quality Assurance (QA) supervisors, QA floor-level surveillance specialists, and cost/price analysts as appropriate.

In addition to controlling confounding or extraneous variables, the descriptive study must also meet the challenge of obtaining complete and accurate information. One of the best methods to accomplish this objective is through motivation of the respondent (13:228). Emory noted that motivation can be achieved by establishing good rapport with the respondent, and providing assurances that answers will be kept confidential and used only in combined statistical totals. This study attempted to accomplish respondent motivation by providing the recommended assurances at the beginning of each interview. Further efforts to establish rapport were accomplished by providing background information on the purpose and general focus of the research, as well as background information on the interviewer. Finally, the respondents were requested to provide answers which reflect a policy viewpoint regarding government surveillance, as opposed to personal perspective.

Scoring, Grouping and Summarizing the Data. The first step to provide meaning to the data collected is the development of a scale. Emory described some of the methods used to develop scales (13:258-260), including the consensus scale, in which a panel of judges evaluate the items chosen to determine whether they are relevant to the topic under consideration and unambiguous in implementation. He further stated that this approach can be used to determine the validity of the scale, especially when scaling abstract concepts. Since this study is examining abstract relationships, evaluation of the measurement instrument was accomplished by a group of professors (see appendix C) at the Air Force Institute of Technology (AFIT). Their recommendations regarding the relevance and clarity of the instrument were incorporated prior to the actual interviews.

As noted in a previous section, the final scale will be based on the overall responses associated with each investigative question. This technique will result in a scale where the data from the individual investigative questions are used to determine whether relationships exist among process control, productivity and weapon system costs. Data collected and organized in such a fashion is known as nominal or classificatory data. Development of operational definitions to achieve the appropriate classes is described in the next subsection.

The purpose of classification is to facilitate analysis of the data. As noted by Emory (13:369), "Analysis involves breaking down and rearranging data into more meaningful groups to aid the search for significant relationships." Emory called this process coding (13:371), and he recognized that such coding sacrifices some of the detail but is necessary for efficient analysis. Emory described four tests (13:371-372) to determine whether the categories selected were adequate. This study met the first test -- the categories are appropriate for the research problem and purpose -- when the previously mentioned faculty panel concurred that the research instrument provided information to answer the investigative questions. The next two tests require the categories to be exhaustive and mutually exclusive. The faculty panel also evaluated the interview instrument for these criteria, to assure there was a category for each data item and that each data item fell into only one category. The final test -- the categories are derived from one classification principle -- were met when the panel determined every class in the category set was defined in terms of one concept.

Identification and Classification of Variables. The variables to be evaluated by this study will be based on the operational definitions developed for the four categories described below. As stated by Emory (13:372), one of the functions of such definitions is to provide categories com-

posed of mutually exclusive elements. Emory further stated that operational definitions "should specify the characteristics to be observed and how they are to be observed [13:28]." The purposes cited by Emory will be accomplished in Chapter IV, when the actual operational definitions are derived from the data in the respondents' answers. Since this is a descriptive study, this approach will assure the current study does not prejudice the data, and will permit development of testable variables for follow-on studies.

The four operational definitions to be developed in Chapter IV are: (1) adequate process controls; (2) adequate cost controls; (3) improved productivity; and (4) associated cost reductions. Each variable will be based on the cumulative responses to the four investigative questions described earlier in this chapter. The following subsections describe the validity measures that apply to these variables, and the assumptions and limitations of this methodology.

Evidence of Data Validity. General considerations regarding the validity and reliability of the interview instrument were described in the third section of this chapter. In addition, the validity of the classification scheme was described in the subsection on scoring, grouping and summarizing the data. This subsection is concerned with the validity of the data obtained as a result of the overall methodology. Emory (13:294) provided the following criteria to measure the effectiveness of personal interviews:

> Three broad conditions are needed for a successful personal interview. They are (1) accessibility of the needed information to the respondents, (2) understanding of the respondents of their roles, and (3) motivation of the respondents to accept such a role and fulfill its requirements.

These criteria were met by the methodology described above. As previously noted, the respondents selected were those having direct knowledge of the floor-level controls and cost data at each facility. Consideration was also given to the respondents' understanding and motivation during the interview orientations at each facility.

Two additional tests of data validity were performed by this researcher at each facility. Where supporting evidence was claimed, the researcher verified the data was available and actually represented the respondents' statements. In the second test, the researcher *personally reviewed* the checklists used by the government personnel to evaluate the contractors' process and cost controls. As described in the "Vita" included with this report, this researcher's background provides the necessary expertise to evaluate checklists developed to assess the adequacy of quality assurance controls implemented in accordance with MIL-Q-9858A and MIL-STD-1520A.

Assumptions and Limitations. As noted in the section justifying the methodology selected, there are both time and money constraints which limited the depth of this research project. In addition to the previously identified time constraint, it must be recognized that the selected methodo-

logy was further limited by the time available for on-site interviews. The facilities meeting the population dimensions described above were located throughout the continental U.S. Because of commitments to attend regularly scheduled classes in the researcher's graduate program, there was a limited period of time between academic quarters in which to accomplish the interviews at these remote facilities. Together with the previously identified cost constraint, this final time constraint dominated the decision to limit the sample size for this study.

According to Emory (13:148-149,152,160-164,299-301), sample size is but one of three considerations the researcher must make to reduce bias in personal interview situations. The other two considerations -- nonresponse and response error -- are discussed below. In discussing sampling error, Emory noted that the attribute measures used with nominal data are the variance and standard error (or standard deviation). He provided a formula to determine an appropriate sample size based on subjective decisions regarding the interval size and degree of confidence desired, corrected for a finite population. This formula is listed below as equation (1):

$$\text{std error} = [pq/(n-1)]^{1/2}[(N-n)/(N-1)]^{1/2} \tag{1}$$

where: p = proportion of population having an attribute
q = proportion of population not having an attribute
N = size of population
n = size of sample

Emory noted that it is possible that the researcher has no information regarding the probable values for _p_ and _q_; in such cases, the researcher can assume _p_ = 0.5. In this study, this assumption was made in order to evaluate the most appropriate sample size. In addition to assuming the value of _p_, a decision was made to assume a sample interval of +/- 0.1 around the assumed _p_ value and a confidence level of 95%. Using these values in equation (1), an appropriate sample size can be calculated by solving the equation for _n_. The basic equation is:

$$0.1/1.96 = [(0.5)(0.5)/(n-1)]^{1/2}[(43-n)/(43-1)]^{1/2}$$

The value 1.96 in this equation is associated with the 95% confidence level (13:163). The solution of this equation indicated the appropriate sample size would be 30.23 (rounded to 31) to obtain the desired interval and confidence level. Obviously, this sample size was impractical in light of the time and money constraints, so it was assumed that the sampling error could not be controlled in this study. Even with a wider interval (+/- 0.2) and a reduced confidence interval (90%), the required sample size would have been prohibitive. As a result, the operational definitions developed in Chapter IV will prescribe the acceptable levels of accuracy for this study. The actual standard error and confidence level will also be calculated in chapter IV based on data gathered during the on-site surveys.

The second source of bias identified by Emory (13:299) -- nonresponse error -- results when a respondent selected for the sample cannot be located. This source was not considered a problem for this study, as the preliminary contact with the various plant representative offices indicated a high degree of acceptance for a planned visit. The third source of bias in personal interview situations -- response error -- occurs when a respondent reports differently than the actual facts (13:301). As noted in the preceding subsection, a number of tests were used during the interviews to assure the validity of the data reported by the respondents.

Two final assumptions must be made about the proposed methodology. First, the independence of the sample facilities visited is generally considered necessary in order to generate valid results (13:413). This requirement was assumed to be met because the various facilities are widely dispersed and each is headed by a single military Commander. Second, since the various test prescribed for the interview instrument were met, the data obtained can be generalized to the entire population. This generalization applies to plant representative office known as ARPROs and NAVPROs, even though none were selected for evaluation as a result of the small sample size and the random sampling techniques.

Statistical Tests

This final section briefly describes the statistical tests which are normally applied to personal interview data. However, because of the limitations of the proposed sample size and the associated risk of sampling error, these tests will not be applied to this data set. Instead, this researcher will report the exact number and kind of responses to each investigative question. The results will then be further reduced by comparing the cumulative responses to the operational definitions developed in Chapter IV. The reasons for reporting exact values were described by Emory (13:380), when he noted that percentages hide the base from which they have been computed, especially when categories have been made up of small numbers as are inherent in this methodology.

Emory (13:388-390) described a method to analyze nominal data for correlation. In his methodology, he required classification of each variable into two or more categories, followed by a cross-classification of each variable into a two-way table. This technique facilitates analysis of the data, and also prepares the data for later statistical tests. This classification process will be accomplished in Chapter IV to portray any relationships that might exist, but no further statistical analysis will be performed for the reasons described above.

In terms of actual statistical tests, Emory (13:405-408,413-415,434) described the nonparametric tests normally applied to one-sample nominal data. His description included guidance about assuring statistical significance, developing the null and alternative hypotheses, establishing decision rules for accepting or rejecting the null hypothesis, and using the binomial and C tests. In the case of this study, Emory's guidance is not applicable, but it is recommended that readers review his guidance if they plan to replicate this study or attempt any of the future studies proposed in Chapter V of this report.

IV. Findings and Analysis

Overview

Chapter II of this report contained a review of the literature relating process controls to productivity and cost. It was concluded there was little empirical evidence at this time to relate such variables to each other. This shortcoming in the current literature led to the selection of the survey methodology described in Chapter III, which was developed to answer the following research questions:

1. Are DoD in-plant personnel aware of a relationship between quality assurance process controls and productivity?

2. If such a relationship exists, are associated cost savings passed on to DoD in future weapon system procurements?

This chapter reports the findings generated by the survey described in Chapter III, and provides an in-depth analysis of the results. The body of this chapter begins with a section describing the implementation of the survey and the deviations from the planned design. This description includes a discussion of the validity and reliability measures actually accomplished during the performance of the survey.

This description section is followed by a third section reporting the actual results of the survey and an analysis of those results. The results are initially grouped to provide answers to each of the four investigative questions

described in Chapter III. The third section continues with an analysis of the findings in terms of the investigative questions and the original research questions. This analysis requires a series of data reductions to develop the operational definitions described in Chapter III. This chapter then concludes with a fourth section containing statistical tests appropriate for the methodology developed. These tests will determine whether the data developed by this study can be generalized to the population of plant representative offices identified in Chapter III.

Description of the Survey

Chapter III described the survey design planned for this study. This section describes how the survey was actually accomplished and explains the deviations from the design. This description also includes a discussion of the validity and reliability measures actually performed during the on-site visits to the plant representative offices.

The planned approach called for an in-depth survey of five randomly selected aerospace plant representative offices under the cognizance of various DoD procurement activities. The universe of potential facilities included 43 plant representative offices listed in DoD 4105.59-H, as identified in appendix A, that were currently performing the machining and heat treating operations addressed in the interview instrument. A deviation from this plan occurred when AFPRO General Dynamics, Fort Worth Division, refused

this researcher's request for permission to perform an on-site survey. Their rationale was they had just undergone a similar study, and the available data could be obtained from the Air Force Contract Management Division at Kirtland AFB. However, as noted in Chapter II of this report, this author was unaware of any empirical research designed to test the relationships described by the present study.

The impact of the deviation from the randomness criterion was not considered significant to this study. The sampling plan described in Chapter III called for selection of alternate facilities in case permission could not be obtained to perform on-site surveys. When AFPRO General Dynamics refused access, the next facility on the list was contacted, and the survey was conducted using a sample size of five facilities. The most significant limitation of this study was not the randomness feature, but rather the small sample size. This feature, more than the randomness criterion, contributed to the uncontrolled sampling error reported in Chapter III. The randomness criterion primarily contributes to the generalizability of the data obtained from this study. Generalizations possible from this study are discussed in the final section of this chapter.

A second dimension of the population addressed in the survey design was the requirement that the respondents were administering the floor-level quality assurance program in the plant representative office, and that such respondents

had knowledge of the use and maintenance of contractor quality cost controls. This desire was expressed in both an introductory letter (see sample in appendix D) sent to each plant representative office selected for the study, and during orientation meetings at the start of each interview session. All the plant representative offices visited cooperated fully in this regard, and a number of different personnel participated in the study at each location. This control was used to reduce the extraneous variation typical of ex post facto study designs.

A third feature of the plan described in Chapter III was that interview questions would proceed from the simple to the complex, and from general to specific items of interest. This technique would allow the interviewer to first establish the respondents' frames of reference, and would also limit the distortion effect of earlier questions on later ones. Control was to be accomplished by asking questions in the order listed in the interview instrument contained in appendix A. In the actual surveys, the only deviation from this planned approach occurred when respondents indicated they were unfamiliar with a specific item of interest. In such cases, these questions were postponed for later discussion with personnel more familiar with the item of interest. This action was in consonance with the second control feature described above, and was therefore not considered a detrimental deviation from the plan. In most

facilities visited, the postponed questions had to do with pricing or other contractual features generally beyond the scope of floor-level QA specialists, such as questions 40, 41, 47, 48, 52 and 53 (see appendix A for details).

A fourth feature of the planned methodology involved techniques to obtain complete and accurate information through respondent motivation (13:228). This control was to be accomplished by assuring respondents that their answers would be kept confidential, and by providing respondents with background information about the purpose and general focus of the research and the interviewer's experience. Finally, motivation was to be accomplished by giving respondents the opportunity to compare their personal perspectives with normal policy. No deviation from the planned motivation techniques occurred at any of the facilities visited.

A final control feature of the methodology described in Chapter III required the interviewer to validate the data obtained in the interview sessions. This control was to be accomplished by evaluating supporting evidence to assure the claims made by the respondents were accurate, and by reviewing checklists used by government personnel to evaluate the contractors' process and cost controls. Of particular concern to the researcher were claims regarding trends in the area of scrap, rework and repair as well as related cost data. No deviations to the plan occurred, as required evaluations were accomplished at each facility visited.

Report and Analysis of the Findings

By summarizing the responses to the specific measurement questions, this section reports the detailed results of the interviews at the five plant representative offices. To provide meaning to the detailed results, the data from the measurement questions were then analyzed in terms of the original investigative questions. The data were then further reduced to develop operational definitions, and the relationships between process control, productivity and cost were examined. This final reduction provided the data to resolve the original research questions, and also provided testable variables for follow-on studies.

Evaluation of Production and Manufacturing Processes. As described in Chapter III, this first group of measurement questions was developed to investigate the question,

> 1. *How do DoD* in-plant personnel evaluate contractor control of production and manufacturing processes?

This group of measurement questions was subdivided to evaluate three areas of process control: general issues, machining and heat treating operations. The responses to the first eight "general issue" measurement questions are summarized in Table I. Key words from each question are used as referents for the responses tabulated. Where specific follow-on questions were contained in the interview instrument, such as the relationship between questions 4 and 5, the combined responses to both questions are provided in the table.

TABLE I

Summary of "General Issue" Responses

Ques.	Referents	Results	Rating *
1	contract quality reqmts	* all 5 facilities had contracts containing MIL-Q-9858A	n/a
		* 3 of the 5 also had contracts containing NHB 5300.4B, the NASA Quality Program specification	n/a
2	DoD surveillance manual	* 2 of the 5 used DLAM 8200.1 exclusively	n/a
		* 2 of the 5 used AFR 74-1 and AFCMDR 178-1 exclusively	n/a
		* 1 of the 5 used all three manuals listed	n/a
3	contractor process surveillance	* all 5 facilities used in-process and/or final inspection	n/a
		* 4 of the 5 also used periodic internal audits of the processes	n/a
4 & 5	govt process evaluation	* all 5 facilities used 1st piece, in-process and final inspections, tooling, further assy checks (where applicable), and NDI/NDT	1.0
		* all 5 employed some level of process audit to ensure compliance with required procedures	n/a
6	equip capability and qualification	* 3 of the 5 performed some govt evaluation of these elements	0.6
7	special operating environments	* only 2 of the 5 had reqmts for environmental controls -- each of these used govt audit to verify compliance	1.0
8	compliance with work instructions	* 2 of the 5 used a combination of product inspection and audit to verify this reqmt, and the remaining 3 facilities relied solely on audits to verify this reqmt	1.0

* Ratings represent the percentage of positive responses.

The last two "general issue" questions, numbered 9 and 10 on the interview instrument, obtained the respondents' definitions of process control and process yield. A composite definition, based on repetitive elements in each respondent's answer is reported below:

> <u>Process Control</u> is an assessment of the adequacy of and compliance with procedures and work instructions that control the elements of the process that affect product quality.
>
> <u>Process Yield</u> is a measure of the efficiency of the process in terms of output of product that meets specification requirements.

Later in this section, these definitions and those provided in Chapter I will provide a frame of reference for the development of the operational definitions proposed for use in follow-on studies. In addition, the "rating" column in this and other tables will be used in the operational definitions to evaluate the original research questions.

The second group of measurement questions associated with the first investigative question is summarized in Table II. This table covers questions 11 through 23 on the interview checklist, which were referred to as the "machining operation" questions in the preceding chapter. The final series of measurement questions associated with this first investigative question were identified as "heat treating operation" questions. This element of process control was addressed by questions 24 through 31 on the interview checklist. The responses to this final subgroup of questions are summarized in Table III.

TABLE II

Summary of "Machining Operation" Responses

Ques.	Referents	Results	Rating
11	basic machining operations	* all 5 facilities had some form of metal removing operation	n/a
		* 4 of the 5 had some type of shaping operation	n/a
12 & 13	equip maint and calibration	* 4 of the 5 had some govt evaluation of maint records	0.8
		* 4 of the 5 had govt evaluation of calibration records, with 1 of the 5 witnessing the calib.	0.8
14 & 15	tooling/fixture qualification, calib. and wear	*4 of the 5 contractors were required to check for tool wear and calib based on usage or time	n/a
		* 4 of the 5 had periodic govt evaluation of tooling qualification and calibration	1.0
16	lubricants and cooling oils	* 2 of the 5 had some govt evaluation of lubricants as part of equip maint	0.4
17	set-up, feeds and speeds	* 2 of the 5 had some govt evaluation of these elements	0.4
18	inserts & offsets	* none of the facilities had any govt evaluation of this element	0.0
19	depth of cut	* 1 of the 5 had some govt verification of this element	0.2
20 & 21	statistical analysis	* 4 of the 5 contractors were required to use statistical control and 2 of these 4 had some govt evaluation of the contractor data	0.5
22 & 23	advanced mach techniques	* all 5 used N/C equip	n/a
		* 2 of the 5 used CAD/CAM	n/a
		* 2 of the 5 used robotics and integrated gaging	n/a
		* 1 of the 5 had govt evaluation of N/C tapes, and 1 of the 5 had inspection of hardware made on N/C equip	0.4

TABLE III

Summary of "Heat Treating Operation" Responses

Ques.	Referents	Results	Rating
24	type of heat treat	* 3 of the 5 treated both steel and aluminum	n/a
		* 1 of the 5 treated only steel	n/a
		* 1 of the 5 treated only aluminum	n/a
25	preparations for heat treating	* only 1 facility had any govt verification of the preparations	0.2
26	rate of heating and soak time	* 4 of the 5 had govt verification of the contractor records of time, temp and pressure	0.8
27	quenching	* 2 of the 5 had govt evaluation of this element	0.4
28	annealing	* only 2 of the 5 contractors were annealing parts, and only 1 govt activity was verifying the contractor controls	0.5
29	contractor testing	* 4 of the 5 contractors used lab testing, with the 5th relying solely on hardness tests	n/a
30 & 31	govt verification of contractor testing	* all 5 facilities had some form of govt evaluation of contractor test records, and 2 of the 5 actually witnessed some of the tests	1.0

In general, the answer to the first investigative question is a composite of the responses summarized in the first three tables of this section. Table I addressed "general issues" associated with process control. Since all the facilities visited contained requirements for a MIL-Q-9858A Quality Program or its NASA NHB 5300.4B equivalent (see question 1), the contractors' process controls should encompass all the elements listed in Chapter II of this report, as examined by the individual measurement questions. This was generally true, with the exception of the one facility that did not perform internal audits (see question 3). The government surveillance of such programs should also be similar, except as permitted by peculiar DoD manuals (see question 2). However, the responses to questions 4 through 8 indicated this was not the case. The difference in Government surveillance levels becomes even more obvious as the results of Tables II and III are evaluated.

Table II addressed specific process controls normally associated with "machining operations." The individual measurement questions were based on process controls identified in Chapters II and III of this report. Since most of the contractors used similar machining operations (see questions 11 and 22), and had similar control for tooling and fixture wear (see question 14) and statistical analysis (see question 20), the level of government surveillance should be

similar. However, the responses to questions 12, 13, 15-19, 21 and 23 indicate a wide range in the level of government surveillance of the cited process controls.

Table III addressed specific process controls normally associated with "heat treating operations." These individual measurement questions were also based on typical process controls identified in Chapters II and III. Again, the contractor controls were generally consistent (see questions 24 and 29); but, as demonstrated in the responses to questions 25-28, 30 and 31, the level of government surveillance of these control elements again differed.

Because of the varying levels of government surveillance, the overall response to this first investigative question must be qualified. While the major aerospace facilities visited manufactured quite different products, the contractors generally employ similar process controls to meet the requirements of MIL-Q-9858A and/or NHB 5300.4B. The government personnel responsible for evaluating these process controls generally perform some surveillance, but the individual process control elements evaluated appear to be at the discretion of the government personnel assigned to each facility. This difference will be discussed in more detail in Chapter V.

Evaluation of the Contractor Cost Controls. This group of measurement questions was designed to investigate the following question,

> 2. How do DoD in-plant personnel evaluate the contractor's cost controls?

The responses to questions 33 through 39 provide the data to resolve this question. These responses are summarized in Table IV. In addition, a composite of the respondents' definitions of nonconforming material, provided in response to question 32 on the interview instrument, is reported below:

> Nonconforming Material is any product that does not conform to specification, drawing or contract requirements.

As noted in Chapter III, nonconforming material is correlated with cost control in the government specifications cited in this report (9; 35). When compared with the other data reported in this section, this composite definition of nonconforming material will contribute to the development of the second operational definition proposed for use in follow-on studies. The actual operational definitions are contained in a later subsection of this chapter.

As above, the answer to this question is a composite of the responses summarized in Table IV. In general, the contractors had similar requirements for the control of nonconforming material and the cost of quality (see question 33). Most of the contractors also performed some trend analysis of their nonconforming material and cost of quality

TABLE IV

Summary of Cost Control Responses

Ques.	Referents	Results	Rating
33	contract provisions	* all 5 facilities had reqmts for maintenance of cost of quality data under MIL-Q-9858A	n/a
		* 2 of the 5 had nonconforming material per MIL-STD-1520A	n/a
		* 1 of the 5 had nonconforming material per DLAM 8200.1	n/a
		* 2 of the 5 used MIL-STD-1520A or DLAM 8200.1 depending on the program	n/a
34	govt role on rework, repair and scrap	* when MIL-STD-1520A applied, the contractor dispositioned rework, scrap and standard repairs w/o prior govt approval	1.0
		* when DLAM 8200.1 applied, the govt provided prior approval on all MRB actions	n/a
35 & 36	trend analysis	* 4 of the 5 had contractor data available, and the govt performed some review of the data	0.8
37	product quality and sampling	* only 1 contractor regularly used samples based on prior history; the others performed primarily 100% inspection, due to contract reqmts or small lots	n/a
38	quality cost analysis	* 4 of the 5 facilities had some govt analysis of contractor cost data, and the 5th facility had the MIL-Q-9858A reqmts waived by the PCO	1.0
39	overall discrepancy costs	* 2 of the 5 had govt evaluation of replacement costs	0.5
		* 3 of the 5 had govt evaluation of reinspection costs	0.75
		* 1 of the 5 had govt evaluation of repair/overhaul data only	n/a
		* 1 of the 5 had the MIL-Q-9858A reqmts waived by the PCO	n/a

data (see question 35). Only in the areas of reduced inspection (see question 37) did the contractor approaches truly differ, but this difference was generally due to contract requirements and/or small lot sizes of production hardware.

The level of government surveillance of contractor cost controls, as demonstrated by the responses to questions 34, 36, 38 and 39, was much more consistent than that reported for process controls. The only real variance occurred in the area of evaluating overall discrepancy costs (see question 39), but the majority still performed some surveillance of this control element. The response to this second investigative question is: government QA personnel generally assess all the elements of cost control identified in chapters II and III.

Relationships Among Process Controls, Cost and Productivity. The third group of measurement questions developed in Chapter III was designed to investigate the question,

> 3. If the DoD in-plant personnel evaluate the process controls, how do they define a relationship between such controls and productivity or cost?

The responses to the measurement questions numbered 40 through 47 provide the data to resolve the third investigative question. The results are summarized in Table V. This data will be combined with that developed in response to the fourth investigative question (reported in the next subsection) to develop the last two operational definitions.

TABLE V

Summary of Relationship Data Responses

Ques.	Referents	Results	Rating
40	ManTech and TechMod funding	* 4 of the 5 contractors were receiving funds for one or both of these programs, which resulted in improved capital equip	n/a
		* the 5th facility received no special funding, but did receive new capital equip as GFP	n/a
41	use of capital equip	* only 2 of the 5 have documented productivity improvements related to new capital equip	0.4
42, 43 & 44	corrective action and productivity	* in 2 of the 5, the govt reported effective C/A reduced the levels of nonconforming material	0.8
		* 2 of the 5 reported short-term improvements, but no long-term reductions	n/a
		* the 5th facility reported very little C/A due to low rates of new production hardware	n/a
45	rework and repair related to productivity	* 3 of the 5 reported reductions in rework and repair	0.6
		* 1 of the 5 reported little rework and repair due to low rates of new production	n/a
		* the 5th facility had no govt review of rework and repair data	n/a
46	productivity trends	* 4 of the 5 reported overall productivity improvements	0.8
		* the 5th facility had no govt data on which to evaluate trends	n/a
47	effect of process control and productivity on costs	* in 4 of the 5, the govt noted reduced costs due to productivity improvements in mach and H/T areas	0.8
		* in the 5th facility, the govt was unaware of any cost data to support or refute improvement in the mach and H/T areas	n/a

As was done with the preceding investigative questions, this question will be resolved by a composite response based on data contained in Table V. While all the contractors were receiving funds to procure new capital equipment (see question 40), the government was only aware of documented productivity improvements associated with capital equipment in two of the contractor facilities (see question 41).

Using the definitions of yield and nonconforming material developed above, the effect of corrective action on the causes and the levels of nonconforming material (see questions 42-44) was not considered a long term contributor to increased productivity or yield in most of the facilities. The effect of the contractors' efforts to control rework and repair levels (see question 45) was considered a contributor to increased productivity or yield at most of the facilities. Government personnel generally found the overall productivity trends and cost data for the machining and heat treating operations (see questions 46 and 47) to be improving. As a result, the response to the third investigative question indicates a positive relationship among process controls, productivity and cost are probable. This finding will be further evaluated in a later subsection, using the data from the fourth investigative question and a cross-classification table.

Evaluation of Supporting Data. This final group of measurement questions was designed to investigate the question,

> 4. What data is available to demonstrate relationships among process controls, productivity improvement and reduced costs?

The responses to this group of measurement questions, numbered 48 through 53, are summarized in Table VI. As noted in the preceding subsection, the data from these questions will be combined with that data summarized in Table V to develop the last two operational definitions. The data in these last two subsections will ultimately provide the results necessary to address the shortcomings of the present literature so often cited in this report. This point will be discussed at length in Chapter V.

Like the others, the answer to this investigative question is a composite of the responses summarized in Table VI. As before, similar circumstances existed for each of the contractors (see questions 48-50). All five contractors maintain detailed cost and trend data, and such data is made available for government review. However, the contractors are apparently not provided contractual incentives to increase productivity, even though the literature reviewed in Chapter II indicated such provisions should be considered when developing Tech Mod programs (10:121).

TABLE VI

Summary of Supporting Data Responses

Ques.	Referents	Results	Rating
48	contract incentives to improve productivity	* none reported by govt	n/a
49 & 50	cost and trend data	* all 5 contractors collected detailed cost and trend data	n/a
		* only 2 of the 5 were contractually required to deliver copies of the data to the govt, but all five made the data available for govt review	1.0
51	validity and accuracy of data	* 4 of the 5 govt offices verify the contractor maintains required data, *but only 1 office* considered their review a validation of that data	0.2
52 & 53	productivity improvements and reduced costs	* 1 of the 5 govt activities reported a price reduction due to data on productivity improvement	0.2
		* 3 of the 5 govt activities had data on the mach and H/T areas, but such data was not evaluated unless threshholds were exceeded	n/a
		* all 5 govt activities evaluate direct cost and overhead; in all but one facility, reductions were based on historical contractor data, and did not include an analysis of productivity data	0.2

The government surveillance levels and use of available data, as demonstrated in the responses to questions 51-53, varied considerably. While most of the government QA personnel did verify the contractor maintained the required data, only one of the plant representative offices attempted to validate the accuracy of the data. Most of the Government offices had data available on costs in the machining and heat treating areas, but only one of the offices reported a price reduction directly associated with productivity improvements. And finally, while all the government activities evaluated related costs such as direct labor and overhead, only one included an analysis of productivity to determine whether cost savings were appropriate.

As a result of the foregoing considerations, the answer to this final investigative question must also be qualified. While the data supports a relationship between process controls and productivity improvement, the responses to this group of questions do not support a relationship between these factors and reduced weapon system cost. Further analysis of this issue occurs below, when the relationships are examined in terms of the original research questions.

A final group of questions in the survey instrument sought to determine personal data about the respondents. However, as noted in Chapter III, this data was only intended for follow-up by the researcher. As such, no summaries of the personal data will be provided in this report.

Development of Operational Definitions. As noted in Chapter III, operational definitions "should specify characteristics to be observed and how they are to be observed [11:28]." The four operational definitions, or variables, called for in Chapter III were: (1) adequate process controls; (2) adequate cost controls; (3) improved productivity; and (4) associated cost reductions. Based on the data contained in Tables I through VI, and the analyses provided in the preceding subsections, the following operational definitions will be used to determine whether relationships exist between process controls, productivity and reduced weapon system costs. As noted in Chapter III, some information is lost when data are reduced and manipulated, especially when using small sample sizes. However, the only way to add meaning to the large amount of data contained in Tables I through VI is to reduce it to categories that facilitate analysis.

Adequate Process Controls. This characteristic is based on the composite response to the first investigative question. The characteristic should be observed in the fashion described in the preceding analysis; that is, by comparing the process control requirements levied on the contractors with the level of surveillance performed by the cognizant government plant representative offices. This approach is consistent with the composite definition of "process control" provided earlier in this section.

Where similar requirements are levied on the majority of the contractors, the adequacy of the process controls is determined by subjective and widely varying evaluations by the government personnel, but at least some of the listed control elements are evaluated at all of the plant representative offices. The value assigned this characteristic is calculated by averaging the percentage of plant representative offices that evaluated the elements indicated by questions 4-8, 12, 13, 15-19, 21, 23, 25-28, 30 and 31. This percentage is indicated by the "rating" assigned each question in the various tables. Equation (2) will simplify this calculation:

$$APC = (\sum x)/n \qquad (2)$$

where: APC = adequate process controls
x = ratings assigned individual questions
n = number of ratings given

Using the data from Tables I through III in equation (2), the value for this characteristic is:

$$APC = 11.0/18 = 0.61$$

Since questions 5 and 31 follow-up questions 4 and 30 respectively, only 18 elements are represented in this calculation. In addition, where less than five contractors performed a specific function (as indicated by the responses to questions 7, 14/15, 20/21, and 28), the rating assigned that element is based on the percentage of contractors performing

the function. The APC value calculated above will be used again in the cross-classification tables developed in the next subsection.

Adequate Cost Controls. This characteristic is based upon the composite response to the second investigative question. It too should be observed in the fashion described in the preceding analysis; that is, by comparing the cost control requirements levied on the contractors with the level of surveillance performed by the government plant representative offices. Where similar requirements and levels of data analysis apply to the majority of the contractors, the adequacy of the cost controls is determined by government surveillance of all of the control elements listed at the majority of the facilities visited. This approach is consistent with the composite definition of "nonconforming material" provided earlier in this section, in that the operational definition stresses those activities necessary to verify contractors' efforts to control nonconforming material.

The value assigned this characteristic is based on the average number of plant representative offices that evaluated the cost control elements listed in questions 34, 36, 38 and 39. This percentage is indicated by the "rating" assigned each question in Table IV. Equation (3) will simplify this calculation:

$$ACC = (\sum y)/n \tag{3}$$

where: ACC = adequate cost controls
y = rating assigned questions 34, 36, 38 and 39
n = number of ratings given

Using the data from Table IV in equation (3), the value for this characteristic is:

$$ACC = 4.05/5 = 0.81$$

For question 34, positive action was assured because all five facilities had acceptable government evaluation regardless of which specification applied. The ratings assigned questions 38 and 39 are based on the number of contractors required to maintain such data. The ACC value calculated above will also be used in the cross-classification tables developed in the next subsection.

Improved Productivity. This characteristic is based upon the composite response to the third and fourth investigative questions. It is observed by comparing the factors of productivity improvement with the supporting data analysis. Improved productivity will be deemed to have occurred if the claimed trends in the productivity factors evaluated are improving based on actual government validation of the data. The value assigned this characteristic is calculated by averaging the number of facilities that claimed improvements for the factors identified in questions 41-46, then weighting this percentage by the percentage of

the positive responses to question 51, where a positive response means that validation has occurred. Equation (4) will simplify this calculation:

$$IP = a[(\sum z)/n] \tag{4}$$

where: IP = improved productivity
z = ratings assigned to questions 41-46
a = rating assigned to question 51
n = number of improvement factor ratings given

Using the data from Tables V and VI in equation (4), the value for this characteristic is:

$$IP = (0.2)(2.6/4) = (0.2)(0.65) = 0.13$$

The IP value calculated above is sensitive to both the level of claims made regarding improved productivity and the amount of government validation of such claims. Since questions 42, 43 and 44 were all interrelated, only four elements were considered in developing the number of improvement factors. As will be done with the values from the preceding operational definitions, the IP value calculated above will be used in the cross-classification tables in the next subsection.

<u>Associated Cost Reductions</u>. This characteristic is also based on the composite responses to the third and fourth investigative questions. It is observed by comparing claimed cost reductions with the supporting data analysis. Associated cost reductions will be deemed to have occurred if the claimed cost savings are shown to have resulted in

reduced costs to the government. The claimed cost savings were based on data provided to the government by the contractor machining and heat treating departments. This data must have been subjected to validation by on-site government personnel, and shown to have resulted in reduced costs as verified by this researcher. The value assigned this characteristic is calculated by weighting the percentage "rating" of facilities responding positively to question 47 with the average of positive responses to questions 51, 52 and 53. Equation (5) will simplify this calculation:

$$ACR = b[(\sum c)/n] \tag{5}$$

where: ACR = associated cost reductions
b = rating assigned to question 47
c = ratings assigned to questions 51, 52 and 53
n = number of supporting data ratings given

Using the data from Tables V and VI in equation (5), the value for this characteristic is:

$$ACR = 0.8(0.6/3) = 0.8(0.2) = 0.16$$

Like the preceding IP calculation, the ACR value calculated above is sensitive to the level of claimed cost savings and the amount of government validation of such claims. In this instance, three ratings were considered to develop the support data average. The first two categories of responses to questions 52 and 53 actually addressed the same issue, and were thus considered as one combined response. The responses to question 51 and the third category under qestions

52/53 made up the remainder of the supporting data average. Like the other three operational definition values calculated in this subsection, the ACR value calculated above will be used in the cross-classification tables developed in the next subsection.

The respondents were asked to consider their definitions of "yield" and "nonconforming material" (provided above) when answering the questions involved in developing the last two operational definitions. This approach assured these operational definitions were consistent with the definitions of "productivity" and "yield" provided in Chapter I of this report. In light of that consistency, the next subsection will examine the relationships described by these operational definitions in terms of the original research questions.

Relationships Examined in Terms of the Original Research Questions. As noted at the beginning of this section, the categories developed in analyzing the four investigative questions above could be used to test whether relationships exist between process controls, productivity improvements and reduced weapon system costs. This testing will be accomplished by a final data reduction, in which the preceding operational definitions are cross classified as shown in Tables VII and VIII.

TABLE VII

Relationship Between Process Controls and Productivity Improvement

	Process Control Value	Productivity Improvement Value
APC	0.61	--
ACC	0.81	--
IP	--	0.13

Table VII compares the values derived from the preceding operational definitions, to determine whether a relationship exists between process controls (including cost controls, as correlated in Chapter II) and productivity improvements. This tabular comparison is intended to clarify such relationships, and to resolve the first research question,

> 1. Are DoD in-plant personnel aware of a relationship between quality assurance process controls and productivity?

While the analysis in the preceding subsections might lead to the belief that DoD in-plant personnel are doing a good job evaluating process and cost controls, with a resultant improvement in productivity, Table VII shows a potential weakness in the current DoD approach to contractor surveillance. The adequacy of process control (APC) and adequacy of cost control (ACC) values indicate the majority of the plant representative offices are assuring contractors control these elements. In addition, the DoD in-plant personnel indicated there was an a productivity increase in the

plants which had adequate process and cost controls. However, when the increase in productivity is weighted by the amount of DoD validation of contractor data, as indicated by the improved productivity (IP) value, it might be concluded that claimed productivity increases are tentative at best. Table VII indicates that less than one of every five (0.13 to be exact) facilities would apparently be able to demonstrate a relationship between adequate process (and cost) controls and improved productivity.

TABLE VIII

Relationship Between Process Controls and Reduced Weapon System Costs

	Process Control Value	Reduced Cost Value
APC	0.61	--
ACC	0.81	--
ACR	--	0.16

Table VIII also compares the values derived from the operational definitions to determine whether a relationship exists between the process controls and reduced weapon system costs. This tabular comparison is made to clarify such relationships, and to resolve the second research question,

> 2. If such a relationship exists, are associated cost savings passed on to DoD in future weapon system procurements?

The analysis of Table VII might lead to the conclusion that further analysis of the second research question is impractical. However, the standard error associated with the preceding data (to be reviewed in the next section) indicates this research question should also be evaluated. Like the preceding analysis of the relationships between process controls and productivity improvement, the APC and ACC operational definition values used in Table VIII indicate the contractors are controlling the processes and their associated costs. In addition, the DoD in-plant personnel indicated cost savings were occurring in the heat treating and machining areas. But, the associated cost reduction (ACR) value is weighted by the amount of DoD validation of the contractor data and proof of reduced costs. This analysis indicates there is little likelihood (i.e., in less than one of every five facilities, or 0.16) of cost savings resulting from adequate process controls being passed on to DoD in future weapon system procurements.

The preceding analysis takes a rather narrow view of the relationships that might occur among process controls, productivity and weapon system costs. But, the purpose of an empirical study is to collect verifiable data, and the methodology employed in the instant study assures this purpose was met. Chapter V will identify some of the methods DoD in-plant personnel can use to overcome the weaknesses in their present surveillance methods.

Statistical Tests

One of the assumptions identified in Chapter III was that the sampling error associated with the small sample size used for this study could not be controlled. As noted in Chapter III, this uncontrolled situation would exist for a variety of sample intervals and confidence levels. Equation (1), the formula used to determine the standard error, is restated below:

$$\text{std error} = [pq/(n-1)]^{1/2}[(N-n)/(N-1)]^{1/2}$$

where: p = proportion of population having an attribute
q = proportion of population not having an attribute
N = size of population
n = size of sample

Using this study's population size of 43, a sample size of five, and the value associated with the level of government validation of contractor data (question 51), the standard error associated with one of the "rating" proportions used in this study is calculated as follows:

$$\begin{aligned} \text{std error} &= \{[(0.2)(0.8)]/(5-1)\}^{1/2}[(43-5)/(43-1)]^{1/2} \\ &= (0.16)(0.951) \\ &= +/-\ 0.152 \end{aligned}$$

The same type of calculation can be made using the rating proportion associated with any other question used in this survey. For example, the standard error associated with the rating (0.6) assigned to question 45 would be calculated as follows:

$$
\begin{aligned}
\text{std error} &= \{[(0.6)(0.4)]/(5-1)\}^{1/2}[(43-5)/(43-1)]^{1/2} \\
&= (0.24)(0.951) \\
&= +/-\ 0.228
\end{aligned}
$$

The standard errors calculated above are just two of 32 such calculations that would be required to assess the accuracy of the operational definition values developed in this chapter. The standard errors associated with each of the four rating proportions used to calculate the ACR operational definition would result in a variety of possible values for that operational definition. For example, if all of the maximum possible rating proportions (based on the original rating plus the standard error) were used in equation (5), the ACR value might have been represented as follows:

$$\text{ACR} = 0.952[(0.352 + 0.352 + 0.352)/3] = 0.335$$

In the same fashion, using the lowest possible rating proportions to calculate the ACR value would give a figure of 0.031. If the uncontrolled sampling error assumption was not made in the last chapter, the IP value calculated above should have been reported as 0.16 (+ 0.1750/ - 0.129). These figures indicate the conditions associated with the ACR calculation reported in the last section of this chapter would probably occur 16% of the time, but possibly as often as 33%, or as infrequently as 3% of the time. This degree of inaccuracy is generally unacceptable in an empirical study.

As a result of the calculations of the actual sampling errors associated with the final data reductions reported in the last section, the assumption regarding the uncontrolled sampling error is considered justified. Because of the potential variation in the data demonstrated in the last paragraph, the decision to evaluate the second research question in the last section was also sound. Based on the potential variation in the calculated IP value, it is also possible to state that improved productivity might have been validated in many more facilities, given a larger sample size.

As noted earlier in this chapter, one plant representative office did not permit the requested on-site interview. While this was not considered as significant a deviation as the sampling error problem just described, it should be acknowledged as a potential non response error. In a research study with a limited sample size such as this, the problem created by non response error occurs in the area of generalizability of the data. Although no statistical tests are available to counteract this problem, a solution will be proposed in Chapter V. Because of the assumptions and limitations described in Chapter III, no other statistical tests are appropriate for the data derived above.

V. Conclusions, Implications and Recommendations

Overview

Chapter I introduced the general issue -- the reduction of costs in weapon system acquisitions -- behind the study just reported. The research questions and objectives of this study were also introduced in Chapter I. The ultimate objective of this study was an evaluation of the relationships between quality assurance process controls, productivity and weapon system costs. Chapter II described the relevant literature to support the objectives established in Chapter I. In analyzing that literature, it was determined there was a serious flaw in the current data base, in that there was little empirical evidence relating process controls to productivity and cost.

As a result of the shortcomings in the current literature, a descriptive study was undertaken to develop empirical data relative to the research objectives. Chapter III described the detailed survey instrument used to gather the descriptive data regarding process controls, productivity and cost. The results of these in-depth surveys were reported in Chapter IV, and then analyzed in terms of the original investigative and research questions. Based upon that analysis, it was determined that productivity improvements (and possibly associated weapon system costs), resulting from adequate process and cost controls, were not supported.

The reason the relationships in question were not supported was inadequate government validation of contractor claims for improved productivity and associated cost reductions. The significance of this finding will be examined further in the next section of this chapter. A third section of this chapter will then discuss the practical implications of this study. These implications will be related back to issues previously identified in Chapters II, III and IV. Finally, this chapter concludes with this writer's recommendations for follow-on or revised studies based on the data generated by this report.

Significance of the Findings

The research described in the preceding chapters was designed to gather data for the development of hypotheses to test whether process controls are related to productivity and weapon system costs. This approach was selected because the present literature presented no empirical evidence relating the elements just listed, and because no evidence was presented to demonstrate that cost savings resulting from such relationships were passed on to DoD. This study was only partially successful in terms of these design goals.

The first shortcoming in the present literature -- the lack of empirical data relating process controls to productivity and cost -- resulted from inadequate government testing of the elements of process control described in this study. This study did overcome one aspect of that shortcom-

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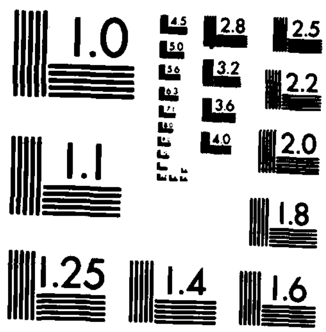
UNCLASSIFIED SEP 84 AFIT/GLM/LSM/84S-50 F/G 15/5 NL


1.0
2.8
2.5
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
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ing by providing a methodology to gather relevant data concerning the relationships that might exist. The failure of this research effort to support the relationships claimed in the literature was not a fault of the study design. As noted in Chapter IV, there is some evidence to show that the issues under investigation are related. However, the present DoD surveillance approach does not provide a method to validate contractor claims regarding productivity improvements which occur because of adequate process or cost controls. The implications of this finding will be discussed in the next section. For now, it can be stated there is a way to address the first shortcoming in the present literature through use of an in-depth survey such as this, and through incorporation of the recommended surveillance method changes described below.

The second shortcoming in the current literature -- the lack of evidence to demonstrate cost savings are passed on to DoD -- was also partially resolved by this study. The methodology used provides a way to determine if cost savings are occurring as a result of adequate process controls and related productivity improvements. As above, the failure of the government in-plant personnel to validate that savings are passed on to DoD can be overcome through changes in the government surveillance methods. But, there is now a method available to overcome the second shortcoming in the present literature.

As a result of the partial success in overcoming the shortcomings of the present literature, this study does provide a base on which to build future studies. The recommended follow-on studies will be addressed in the last section of this chapter. This study does add to the empirical data available to DoD, and has actually built upon that data provided in earlier empirical studies. Various elements of process control identified in the previous studies were incorporated into the interview checklist used in this study. For example, the use of capital equipment in producing better quality products (18:82) was examined, as was the effect of equipment set-up (15:45-46). In addition, two of the previous studies (2; 27) addressed the role of scrap and rework in productivity improvements, and these elements of process control were evaluated by the instant study.

Practical Implications of the Results

Three major recommendations can be made to the DoD community as a result of the findings presented in this research report. The first recommendation results from the discussion in the last section regarding the surveillance methods used by DoD in-plant personnel. The second recommendation addresses the issue of MIL-Q-9858A cost data preparation first identified in Chapter II. The third recommendation is based on observations made during the interviews reported in Chapter IV regarding the role of Tech Mod and Man Tech funding incentives.

DoD Surveillance Methods. As noted in the preceding section, as well as when examining the relationships in terms of the original research questions in Chapter IV, process controls could not be judged positively related to improved productivity or reduced weapon system costs because of inadequate data validation by DoD in-plant personnel. This apparent weakness in the DoD surveillance approach should be examined by all the military departments responsible for major weapon system procurements. Two different approaches are recommended in this regard. The first change requires coordination and improvement in the methods of assessing the adequacy of contractor process and quality cost controls. The second change is related to the pricing and cost evaluations performed by the in-plant personnel.

In terms of assessing the adequacy of contractor process and quality cost controls, a joint service manual has been prepared by the Defense Logistics Agency (DLA). DLAM 8200.1, Procurement Quality Assurance (9), describes the basic surveillance approach to analyzing contractor quality systems and programs. DLA and the other military departments have supplemented this basic manual with other documents and regulations providing additional guidance on monitoring the adequacy of contractor controls. For example, the Air Force has issued AFCMDR 178-1, Contractor Management System Evaluation Program (CMSEP), which addresses quality assurance (QA) and other contractually required management

systems (10). The QA portion of the CMSEP manual is based on H50, the previously referenced document (30) for assessing contractor quality programs implemented in accordance with MIL-Q-9858A. There are numerous other QA manuals used by DLA, the Air Force, the Army and the Navy, but a review of all such manuals is beyond the scope of this study.

While all of the DoD QA manuals have some overlap in the area of in-plant surveillance, those referenced thus far do not require validation of trend or cost data generated by the contractor QA department. In most facilities visited during the course of this study, the DoD in-plant personnel only verified that the contractor maintained the required data. If DoD ever hopes to achieve the level of cost control called for by former Deputy Secretary of Defense Frank Carlucci (5), it is recommended that the various QA surveillance manuals be revised to require validation of the accuracy of the contractor data.

In terms of the second surveillance change recommended above, the military services need to expand their pricing and cost evaluations to assure assessment of productivity and cost improvements which result from adequate process controls. In addition to those military departments mentioned above, the Defense Contract Audit Agency (DCAA) should also be brought into this expanded surveillance approach. It is thus recommended that DoD cost and pricing

personnel be made aware of the potential for cost savings that might occur in the contractor manufacturing and fabrication activities. Where productivity and cost improvements have been validated by DoD QA personnel, such improvements should be considered in follow-on procurement and overhead negotiations.

MIL-Q-9858A Cost Data. Closely related to the proposed changes in DoD surveillance methods is the need for changes in the MIL-Q-9858A requirements for development of contractor QA cost data. While this study confirmed that the contractors do indeed maintain the required data, each of the contractors used a different format and approach to the collection of the data. This fact is unfortunately permitted by the language of MIL-Q-9858A, which states, "The specific quality cost data to be maintained and used will be determined by the contractor [39:3]." If DoD is to be successful in implementing the improved surveillance methods described in the last subsection, the DoD in-plant personnel responsible for evaluating the quality cost data need a uniform format and level of indenture to assure equal standards exist for the assessment and validation of such data.

It is recommended that DoD address this issue by convening a joint military and industry review panel to develop revised standards for the collection of quality cost data. Such data should not just be made available for on-site government review, as is now the case, but should be made a

deliverable data item in all major weapon system procurements. It is recognized that such data must be treated confidentially because of its proprietary nature, but such constraints already exist for much of the cost and pricing data now processed by DoD. Once the data is made available, DoD cost and pricing personnel should review it to validate savings accrued as a result of adequate process controls and improved productivity are passed on to DoD.

Tech Mod and Man Tech Incentives. The final practical implication of the data generated by this study results from observations made in examining the use of capital equipment in the control of the processes. While most of the facilities visited had some new capital equipment which apparently contributed to the control of the processes, there were no contractual incentives provided the contractor to relate the use of such equipment to improved productivity. As previously noted, such incentives are recommended in the Air Force guide to technology modernization (12:121).

It is recommended that the Air Force and other services reexamine the Tech Mod and Man Tech contracts to ensure use of contractual incentives based on increased productivity. Implementation of this recommendation would provide two benefits to DoD. First, it would ensure that some of the elements of process control evaluated in this study are assessed and validated by DoD cost and pricing personnel. Secondly, such a review could consider other factors asso-

ciated with Tech Mod but not presently addressed in the Air Force guide, such as the direct and indirect labor and material cost reviewed by this study. The previously reviewed empirical study by Berry and Bland (2:90) proposed a model which might be considered in the evaluation of this recommendation.

Recommendations for Follow-on Studies

In line with the practical implications of the findings discussed in the last section, a number of studies could be initiated by DoD. The first such study recommended would be a review of the various DoD quality assurance and pricing manuals, directives and regulations to develop a uniform approach to validating and using contractor data on process and productivity trends. Such a study could provide the tools to assure cost savings resulting from adequate process controls are indeed passed on to DoD. A second study in this area could focus on the necessary cost elements to be reported by contractors responsible for developing QA cost controls in accordance with MIL-Q-9858A. The results of such a study could be presented to the previously recommended joint review panel. A third study, to close the loop addressed by the practical implications discussed above, might address the elements of capital equipment productivity measures to be considered in Tech Mod and Man Tech incentive clauses.

In addition to addressing the implications of this study, future research should be considered to build upon the theoretical base of knowledge regarding the relationships among process controls, productivity and weapon system costs. Once better DoD surveillance methods are developed, a follow-on study could be conducted to see if the relationships described in Chapter IV are marginally improved. A number of methodological improvements could be made by expanding the scope of this study. For example, all major weapon system contractors listed in DoD 4105.59-H could be included by developing additional process control questionnaires based on a variety of processes. The operational definitions presented in Chapter IV are not peculiar to the processes evaluated by this study.

This proposed follow-on study could be executed in a couple of different ways. For example, all of the plant representative offices cognizant of major weapon system contractors could be visited or assessed through mail questionnaires, or a larger sample could be drawn that would ensure coverage of plant representative offices from all the services. This approach would overcome the concern for the generalizability of the data developed by the instant study by demonstrating whether the relationships in question hold for Army and Navy plant representative offices (ARPROs and NAVPROs), as well as other Air Force and DCAS plant representative offices (AFPROs and DCASPROs) not covered by this

study. Such an expanded study would also eliminate the uncontrolled sampling error constraint placed on this study by the small sample size. However, problems with non response errors, identified in the last chapter (13:299-301), would become more critical to an expanded study.

An expanded study based on the data generated by this report could increase the reliability of the conclusions developed above. One way to accomplish this objective would be to pre-test the interview instrument along the lines suggested in Chapter III. In addition, the normal statistical tests of nominal data, such as the binomial and C tests described in Chapter III, could be conducted. This approach would provide a measure of the statistical significance of the data generated. But, it would also require satisfactory data regarding positive relationships among the elements studied, so that null and alternate hypotheses could be tested based on a specific set of decision rules.

Finally, other follow-on research might consider elements of productivity not addressed by this report. For example, the Tuttle report (32) mentioned in Chapter II, along with a recently released productivity taxonomy developed by Sink, et al (30), could be used to identify additional elements of productivity for evaluation in a more encompassing follow-on study. The Committee on Naval Shipbuilding Technology (7:28,47) recommended consideration of such factors as management techniques, training, planning,

scheduling, and sequencing of the work operations to improve the processes. According to Hanifin (17:53-54), the effect of design and computer integrated manufacturing systems also have significant impact on quality and productivity. While all of the elements affecting product quality and productivity may be impractical for a single study, smaller studies can be used to build toward a larger, all-encompassing model of the relationships among process controls, productivity and weapon system costs. This study has already contributed to such a model by providing a methodology and empirical data base upon which to build the recommended follow-on studies.

Appendix A: Interview Questions

Evaluation of Production and Manufacturing Processes

General Issues:

1. What are the major contract quality requirements for the products being manufactured at this facility?

2. What is the basic DoD manual you use to develop your surveillance of the contractor's process controls?

3. What type of surveillance does the contractor perform of his machining and heat treat operations?

4. What are the quality assurance criteria that you use to evaluate the contractor's machining operations and special processes?

5. Have you ever considered evaluation of 1st piece, in-process, tooling used as a media of inspection, further assembly, final inspection, NDT/NDI, or product-oriented procedures evaluations (POPE) [select the appropriate categories not mentioned in the preceding answer] to determine the adequacy of the contractor's control of his machining operations and special processes?

6. How do you evaluate the equipment capability (accuracy and precision) and qualification for machining operations and special processes?

7. How do you evaluate special operating environment controls such as cleanliness, temperature and humidity in the manufacturing area?

8. How do you evaluate the contractor's compliance with his work instructions, routing sheets, specifications, drawings and workmanship standards in the manufacturing and special process areas?

9. How would you define process control?

10. How would you define process yield?

Machining Operations:

11. What types of basic machining operations does the contractor perform in-house (e.g., milling, drilling, forming,etc.)?

12. What type of analysis do you perform of the contractor's equipment maintenance, including such actions as trueing the ways and adjusting for spindle wear?

13. How do you verify that the contractor performs the required calibration on his machines?

14. How does the contractor control for wear of his tooling and fixtures?

15. What do you do to verify the contractor's qualification and calibration of his machine tools and fixtures, especially those used as a media of inspection?

16. What type of evaluation do you perform of the lubricants and cooling oils (in terms of specification requirements or operating instructions) used during machining operations?

17. How do you assure that the machine operator uses the proper set-up, and maintains the planned feeds and speeds during production?

18. What type of verification do you perform of the operator's changing of the tooling inserts and compensating machine offsets?

19. How do you evaluate the operator's depth of cut (rough versus finish), and whether the contractor controls this activity to prevent unwanted work hardening and thermal growth?

20. If the contractor uses statistical analysis of his machining operations, what do you do to evaluate these controls?

21. Have you ever considered evaluation of the contractor's x-bar and R charts, the number of standard deviations used in conjunction with such charts, or his analysis of the process variability, including shifting of the process average [select the appropriate categories not mentioned in the previous answer]?

22. What type of advanced machining techniques does the contractor use, such as CAD/CAM, numerical control, robotics or integrated gaging (for automatic size control and cutting tool compensation)?

23. How do you evaluate the contractor's control (e.g., development and use of N/C tapes, operator training, etc.) of these advanced techniques described in the response to the preceding question?

<u>Heat Treating Operations</u>:

24. What type of heat treating does the contractor perform?

25. How do you evaluate the contractor's preparations prior to the heat treat process, such as surface cleanliness and eddy current testing (for electrical conductivity and location in the rack)?

26. How do you verify the rate of heating and soak time?

27. What type of analysis do you make of the quenching operation, including solution temperature and circulation, timeliness and velocity of immersion, and use of appropriate rinses?

28. How do you evaluate the cooling rate when the contractor's procedures call for annealing?

29. What type of testing does the contractor perform to verify the material properties after heat treating?

30. How do you evaluate the adequacy of the contractor's tests described in the previous response?

31. Have you ever considered evaluating properties such as intergranular corrosion, eutectic melting, oxidation, decarburization, and nitriding [select appropriate properties not mentioned in the response to the previous two questions], as required by such specifications as MIL-H-6088F and MIL-H-6875G?

<u>Evaluation of Contractor Cost Controls</u>

32. How do you define nonconforming material?

33. What contractual provisions are in force for control of nonconforming material and cost of quality?

34. What is the government role in evaluating contractor rework, repair and scrap?

35. What type of trend analysis does the contractor perform on rework, repair, scrap and reject rates?

36. How do you assess the contractor's trend data?

37. What role does improved product quality play in allowing the contractor to use sampling in lieu of 100% inspection, or reducing the size of the inspection samples?

38. How do you evaluate the contractor's cost data required by MIL-Q-9858A, especially in the areas of prevention and correction of nonconforming supplies?

39. In addition to scrap, rework and repair costs, how do you evaluate the contractor's overall discrepancy costs, (including such expenses as replacement and retest of defective units and the cost of engineering changes generated as a result of nonconforming material)?

<u>Relationships Among Process Controls, Cost and Productivity</u>

40. What contractual funding does the contractor receive for Manufacturing Technology or Tech Mod?

41. How does the contractor use capital equipment to improve his process controls?

42. What type of corrective action does the contractor typically perform to reduce the causes of nonconforming material in the heat treat or machining departments?

43. What effect does corrective action have on reducing the amount of defective product in the machine shop or heat treat departments?

44. How would you relate the contractor's efforts to reduce the amount and causes of nonconforming material to improved productivity or yield?

45. What effect do you think the contractor's rework and repair efforts have on productivity?

46. Using the criteria from the preceding two questions, what are the productivity trends in the machining and heat treat areas?

47. What effect does the contractor's efforts to improve his process controls and productivity ultimately have on his costs?

Evaluation of Supporting Data

48. What types of contractual incentives are provided to the contractor to improve productivity?

49. What types of cost or trend data does the contractor provide for in-house government review?

50. What types of cost or trend data is the contractor required to submit to the government as deliverable data in accordance with a DD Form 1423?

51. How do you determine the validity or accuracy of the contractor data that is delivered to the government or made available for on-site review?

52. How is the contractor trend or cost data from the machining and heat treat departments used to determine whether productivity improvements result in a reduced cost to the government?

53. How does the government assess the effect of related cost savings (such as reduced direct and indirect labor or overhead costs) which may have resulted from improved process controls or productivity?

Respondent Identification

54. What is your name?

55. What is your organization?

56. What is your title and position within the organization?

57. How long have you held your current position?

58. What prior experience do you have in the subject areas discussed above?

Appendix B: Study Population Listing

#	FACILITY	LOCATION
01	DCASPRO Hayes Int.	Dothan, AL
02	DCASPRO Grumman Aerospace	Stuart, FL
03	DCASPRO AVCO Lycoming Div.	Stratford, CT
04	DCASPRO Sundstrand	Rockford, IL
05	DCASPRO Teledyne CAE	Toledo, OH
06	DCASPRO Williams Int.	Walled Lake, MI
07	DCASPRO Goodyear Aerospace	Akron, OH
08	DCASPRO McDonnell/Rockwell	Tulsa, OK
09	DCASPRO General Dynamics	San Diego, CA
10	DCASPRO Ford Aeronutronic	Newport Beach, CA
11	DCASPRO Westinghouse	Sunnyvale, CA
12	DCASPRO McDonnell Douglas	Huntington Beach, CA
13	ARPRO Textron (Bell Helicopter)	Fort Worth, TX
14	ARPRO Hughes Helicopter, Inc.	Culver City, CA
15	ARPRO Boeing-Vertol	Philadelphia, PA
16	NAVPRO Grumman Aerospace	Bethpage, NY
17	NAVPRO Vought Corp.	Dallas, TX
18	NAVPRO GE (Aircraft Engine)	Lynn, MA
19	NAVPRO Lockheed California	Burbank, CA
20	NAVPRO McDonnell Douglas	St. Louis, MO
21	NAVPRO General Dynamics	Pomona, CA
22	NAVPRO United Technologies	Stratford, CT
23	AFPRO Boeing	Seattle, WA
24	AFPRO Hughes Aircraft	Los Angeles, CA
25	AFPRO Rockwell International	Anaheim, CA
26	AFPRO Rockwell International	Los Angeles, CA
27	AFPRO Rockwell Int. (Rocketdyne)	Canoga Park, CA
28	AFPRO Northrop Corp.	Hawthorne, CA
29	AFPRO Martin-Marietta	Denver, CO
30	AFPRO Douglas Aircraft	Long Beach, CA
31	AFPRO Lockheed-Georgia	Marietta, GA
32	AFPRO Fairchild Republic	Farmingdale, NY
33	AFPRO Hughes Missiles	Tuscon, AZ
34	AFPRO Thiokol Corp.	Brigham City, UT
35	AFPRO GE Aircraft Engine	Cincinnati, OH
36	AFPRO GD, Fort Worth Div.	Fort Worth, TX
37	AFPRO Westinghouse Electric	Baltimore, MD
38	AFPRO Pratt & Whitney	West Palm Beach, FL
39	AFPRO Pratt & Whitney	East Hartford, CT
40	AFPRO Lockheed Missile	Sunnyvale, CA
41	AFPRO CSD Division	Sunnyvale, CA
42	AFPRO Rockwell International	Columbus, OH
43	AFPRO Boeing Military Airplane	Wichita, KS

Appendix C: AFIT Faculty Review Panel

1. Dr. Virgil Rehg is a Professor in the Organizational Sciences Department in the AFIT School of Systems and Logistics. Dr. Rehg teaches courses in Organizational Behavior that emphasize the importance of productivity measures including quality control. Dr. Rehg also teaches courses in Quality Circles in the AFIT Continuing Education Department.

2. Professor Michael Schubert teaches Continuing Education courses in Quality Assurance and Quality Control. Mr. Schubert has many years experience as a Quality Manager and Quality Engineer in industrial settings.

3. Cdr Rudy Weigand, USN, is Head of the Math Department in the AFIT School of Engineering. Cdr Weigand teaches the Applied Statistics for Managers I and Applied Statistics for Managers II courses in the AFIT School of Systems and Logistics.

Appendix D: Sample Introductory Letter

21 May 1984

REPLY TO:

SUBJECT: Plant Visit to Gather Thesis Data

TO: Commander
AFPRO -----

1. Reference: Telecon between Mr. ----- and Mr. M. O'Meara, dated 18 May 84, same subject.

2. Request permission for Mr. Michael W. O'Meara to visit your offices to collect data for an Air Force sponsored Master's Thesis. Mr. O'Meara's research is designed to evaluate the relationship between process controls, productivity and weapon system costs. The data he proposes to collect will be gathered by on-site interviews and record reviews. He will need to interface briefly with QA Supervisory and Technical Specialists, and Contracting personnel familiar with the contractor's financial proposals. It is estimated that Mr. O'Meara can gather the necessary data in four to six hours. All data regarding the facility, programs and personnel interviewed will be kept strictly confidential, and the final report will be based on summarized results from all facilities visited.

3. Mr. O'Meara has made preliminary contact with Mr. -----. They have tentatively agreed to a visit date of 20 Jun 84. With your permission, Mr. O'Meara will reconfirm this date within the next two weeks. Required security clearances will be forwarded prior to the visit. Mr. O'Meara has a ----- security clearance.

Commander

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VITA

Michael W. O'Meara was born on 16 January 1948 in Cleveland, Ohio. He graduated from high school in 1965, and obtained an Associate of Arts degree in Chemistry from Cuyahoga Community College in June 1968. Mr. O'Meara graduated from Ohio State University in December 1971 with the degree of Bachelor of Science in Psychology. He joined the federal service in September 1972. After completing the Defense Logistics Agency (DLA) Quality Assurance (QA) Staff Development Intern program in February 1976, Mr. O'Meara became a QA Staff Specialist with the Defense Contracts Administration Services Region (DCASR) Cleveland. While in this position, he was selected for the FY 78 DCASR Cleveland Executive Development Program. In July 1979. Mr. O'Meara accepted a reassignment to an Operations Branch Chief position in the Defense Contracts Administration Services Management Area (DCASMA) Seattle QA Division. Since December 1980, he has served as the QA Division Chief at Defense Contracts Administration Services Plant Representative Office (DCASPRO) Williams International, Walled Lake, Michigan. While in this position, he was selected for the DLA Executive Development Program, which he began upon entering the School of Systems and Logistics, Air Force Institute of Technology, in June 1983.

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Title: AN ANALYSIS OF THE EFFECT OF PROCESS CONTROLS ON PRODUCTIVITY AND WEAPON SYSTEM COSTS IN DOD PROCUREMENT

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This study was a preliminary evaluation of the relationships among quality assurance process controls, productivity and weapon system costs. The available literature indicated positive relationships should exist among the three elements examined, but little empirical evidence was presented to support the positions of the authors. As a result, a detailed interview methodology was developed to describe the relationships that exist at major DoD aerospace facilities. On-site interviews were conducted at five randomly selected aerospace facilities identified as DoD Plant Representative Offices. The results of this initial study were inconclusive. The examined relationships appeared to be positive, but the cognizant DoD personnel had not validated the contractor data claiming increased productivity and reduced costs associated with adequate process controls. Recommendations are provided to improve the DoD surveillance methods, and possible follow-on research topics are identified.

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